NATURAL PHILOSOPHY

STEELE'S SERIES

IN THE

NATURAL SCIENCES.

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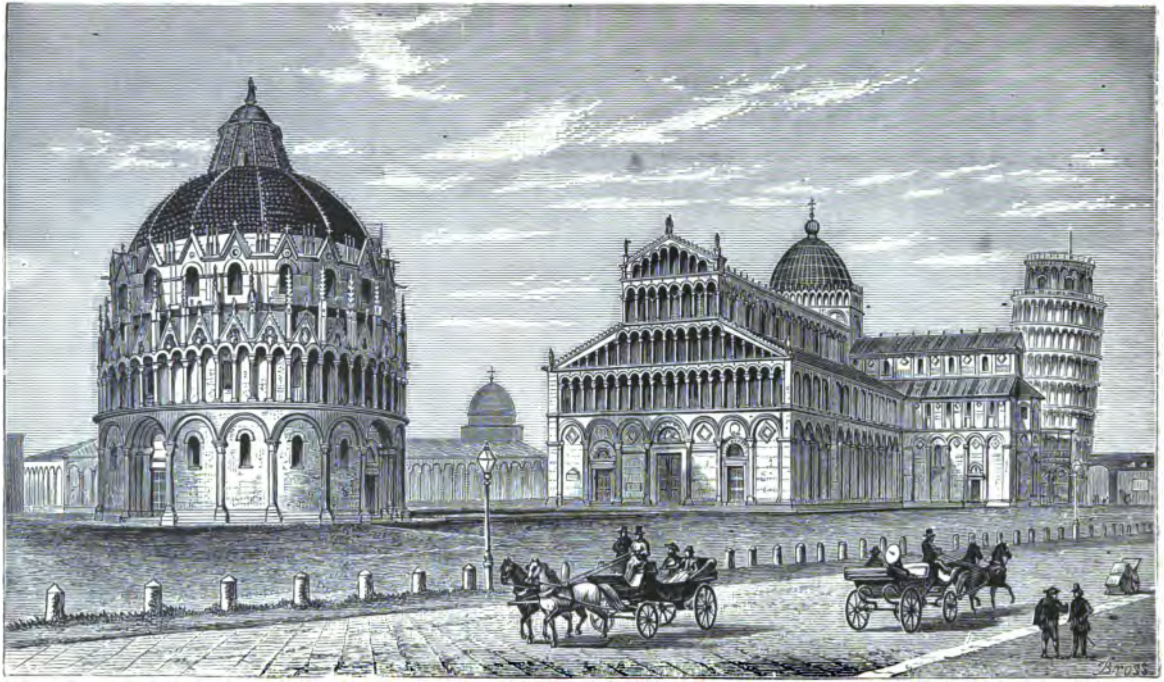

VIEW OF THE SQUARE AT PISA, ITALY.—(*From a Photograph.*)

The Leaning Tower (p. 58) is at the extreme right; next, the Cathedral (p. 65); then, in front, the Baptistry (p. 130); and back of the Baptistry, the Campo Santo, a cemetery containing sacred soil brought by the Crusaders from the Mount of Olives.

STEELE'S NEW PHYSICS.

FOURTEEN WEEKS

IN

PHYSICS.

BY

J. DORMAN STEELE, PH.D., F.G.S.

AUTHOR OF FOURTEEN-WEEKS SERIES IN NATURAL SCIENCE.

'The works of God are fair for naught
Unless our eyes, in seeing,
See hidden in the thing the thought
That animates its being.'

A. S. BARNES & COMPANY,
NEW YORK, CHICAGO, AND NEW ORLEANS.

PUBLISHERS' NOTICE.—The publishers of this book will still issue the former edition, known as "Steele's Fourteen Weeks in Natural Philosophy," for classes already organized and for teachers who may prefer to continue its use. Any bookseller can obtain the former edition if requested to do so. Key containing Answers to the Practical Questions and Problems, Post-paid, $1.25.

BY THE SAME AUTHOR.

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ASTRONOMY.

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PREFACE.

THIS work has grown up in the class-room. It contains those definitions, illustrations, and applications which seemed at the time to interest and instruct the author's pupils. Whenever any explanation fixed the attention of the learner, it was laid aside for future use. Thus, by steady accretions, the process has gone on until a book is the result.

As Physics is generally the first branch of Natural Science pursued in schools, it is important that the beginner should not be wearied by the abstractions of the subject, and so lose interest in it at the very start. The author has therefore endeavored to use such simple language and practical illustrations as will attract the learner, while he is at once led out into real life. From the multitude of philosophical principles, only those have been selected which are essential to the information of every well-read person. Within the limits of a small text-book, no subject can be exhaustively treated. This is, however, of less importance now, when every teacher feels that he must of necessity be above and beyond any school-work in the fulness of his information. The object of an elementary work is not to advance the peculiar ideas of any person, but simply to state the currently-accepted facts and theories. The time-honored classifications recognized in all scientific works, have been retained. In order

to familiarize the pupil with the metric system, now generally used by scientific men, it is continually employed in the problems. The notes contain many illustrations and additional suggestions, but their great value will appear in the descriptions of simple experiments which are within the reach of any pupil.

New plates being required for this edition, the author has taken the opportunity thoroughly to revise the entire work. By carefully comparing the criticisms of teachers, he has tried to obtain the "parallax" of all its statements and methods, and to eliminate, as far as possible, the errors growing out of his "personal equation." Hearty thanks are tendered to the many friends of the book who, by their suggestions and criticisms, have so greatly added to the value of this revision. To name them all in this Preface would be impossible, and to discriminate would be invidious. The author cannot, however, allow the opportunity to pass without expressing his profound sense of obligation. By untiring study and the continued help of his friends, he hopes thus, year by year, to make the series more and more worthy the favor which his fellow-teachers have so abundantly bestowed upon it. Happy indeed will he be if he succeed in leading some young mind to become a lover and an interpreter of Nature, and thus come at last to see that Nature herself is but a "thought of God."

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SUGGESTIONS TO TEACHERS.

SCHOLARS are expected to obtain information from this book without the aid of questions, as they must always do in their general reading. When the subject of a paragraph is announced, the pupil should be prepared to tell all he knows about it. He should *never be allowed to answer a question*, except it be a short definition, *in the language of the book*. The diagrams and illustrations, as far as possible, should be drawn upon the blackboard and explained. Although pupils may, at first, manifest an unwillingness to do this, yet in a little time it will become an interesting feature of the recitation. In his own classes, the author has been accustomed to *place upon the blackboard the analysis of each chapter of the book, and require the pupils to recite from that*, without the interposition of questions, except such as were necessary to bring out the topic more clearly or to throw a side light upon it. Where the analysis given in the book does not include all the minor points of the lesson, the pupils can easily supply the omission. The "Practical Questions" given at the close of each general subject have been found a profitable exercise in awakening inquiry and stimulating thought. They may be used at the pleasure of the instructor. The equations contained in the text are designed to be employed in the solution of the problems.

It should constantly be borne in mind that, as far as possible, every question and principle should be submitted to Nature for a direct answer by means of an experiment. Pupils should be encouraged to try the simple illustrations necessary. The scholar who brings in a bit of apparatus made by himself, does better than if he were merely to memorize pages of text. The following works, to each of which the author acknowledges his obligation for valuable material, will be useful in furnishing additional illustrations and in elucidating difficult subjects, viz.: Tait's Recent Advances in Physical Science:

Arnott's Elements of Physics (7th ed.); Stewart's Elementary Physics, Conservation of Energy, and Treatise on Heat; Atkinson's Deschanel's Natural Philosophy; Lockyer's Guillemin's Forces of Nature; Herschel's Introduction to the Study of Physical Science; Tomlinson's Introduction to the Study of Natural Philosophy; Pepper's Play-book of Science; Beale's How to Work with the Microscope; Schellen's Spectrum Analysis; Lockyer's The Spectroscope and Studies in Spectrum Analysis; Airy's Geometrical Optics; Nugent's Optics; Chevreul on Colors; Thomson & Tait's Natural Philosophy; Maxwell's Electricity and Magnetism; Faraday's Forces of Matter; Youmans's Correlation of Physical Forces; Maury's Physical Geography of the Sea; Atkinson's Ganot's Physics (edition of '77); Silliman's Physics; Tyndall's Lectures on Light, Heat, Sound, Electricity, and Forms of Water; Snell's Olmsted's Philosophy (revised edition); Loomis's Meteorology; Miller's Chemical Physics; Cooke's Religion and Chemistry, and also numerous works named in the *Reading References* at the close of each general division. They may be procured of the publishers of this book. The pupil should continually be impressed with the thought that the text book only introduces him to a subject, which he should seek every opportunity to pursue in larger works and in treatises on special topics.

As heretofore, the author will be pleased to correspond with teachers concerning the apparatus for the performance of the experiments, or with reference to any of the "Practical Questions."

I.

INTRODUCTION.

"*We have no reason to believe that the sheep or the dog, or indeed any of the lower animals, feel an interest in the laws by which natural phenomena are regulated. A herd may be terrified by a thunder-storm; birds may go to roost, and cattle return to their stalls during a solar eclipse; but neither birds nor cattle, so far as we know, ever think of inquiring into the causes of these things. It is otherwise with man. The presence of natural objects, the occurrence of natural events, the varied appearances of the universe in which he dwells, penetrate beyond his organs of sense, and appeal to an inner power of which the senses are the mere instruments and excitants. No fact is to him either final or original. He cannot limit himself to the contemplation of it alone, but endeavors to ascertain its position in a series to which the constitution of his mind assures him it must belong. He regards all that he witnesses in the present as the efflux and sequence of something that has gone before, and as the source of a system of events which is to follow. The notion of spontaneity, by which in his ruder state he accounted for natural events, is abandoned; the idea that nature is an aggregate of independent parts also disappears, as the connection and mutual dependence of physical powers become more and more manifest; until he is finally led to regard Nature as an organic whole, as a body each of whose members sympathizes with the rest, changing, it is true, from age to age, but without any real break of continuity, or interruption of the fixed relations of cause and effect.*"—TYNDALL.

ANALYSIS OF THE INTRODUCTION.

INTRODUCTION.

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I. GENERAL DEFINITIONS.

1. Matter.—Whatever occupies space is called *matter*. A definite portion of matter is termed a *body*. Examples: a lake, a dew-drop, a quart of oil, an anvil, a pendulum. A particular kind of matter is styled a *substance*. Examples: gold, wood, stone, oxygen.

2. General and Specific Properties.—A *general property* of matter is a quality that belongs to all substances. Example: divisibility. A *specific property* is one which distinguishes particular substances. Examples: the yellow color of gold, the brittleness of glass, the sweetness of sugar. These properties are so distinctive that we say, "yellow as gold," "brittle as glass," "sweet as sugar."

3. The Atomic Theory supposes

(1.) That the smallest particle of matter we can see is composed of still smaller particles or *molecules* (tiny masses),* each possessing the specific properties of the substance to which it belongs.

(2.) That each molecule consists of two or more yet minuter portions, called *atoms*,† which cannot be changed

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* A molecule is a group of atoms held together by chemical force, and is the smallest particle of a substance which can exist by itself. Even in a simple substance, *i. e.*, one in which the atoms are all of one kind, it is thought that they are clustered in molecules. (See *Chemistry*, p. 20.) In water, the molecules are the small masses which, when driven apart, form steam. In a gas, they move like so many worlds through space, and striking against the sides of the containing vessel, produce the pressure of the gas to escape.

† Animalcules furnish a striking illustration of the minuteness of atoms. In the drop of stagnant water that clings to the point of a needle, swarming legions swim as in an ocean, full of life, frisking, preying upon one another, waging war, and re-enacting the scenes of the great world about them. These tiny animals possess organs of digestion and assimilation. Their food, coursing in infinitely minute channels, must be composed of solid as well as liquid matter; and finally, at the lowest extreme of this descending series, we come to the atoms of which the matter itself is composed.

by any material force. Examples: a molecule of water is made up of two atoms of hydrogen and one of oxygen. A molecule of salt consists of one atom of chlorine and one of sodium. The smallest piece of salt contains many molecules. By dissolving in water, we divide it into its separate molecules, and the solution has a briny taste, because each one possesses the savor of salt.

4. Physical and Chemical Changes.—A *physical change* is one that does not destroy the molecule, and so does not alter the specific properties of a substance. Examples: the falling of a stone to the ground, the dissolving of sugar in water. A *chemical change* is one that makes new molecules and so destroys the specific properties of a substance. Examples: the rusting of iron, the burning of coal.

5. Physical and Chemical Forces.—A *physical force* is one that produces a physical change in matter. Examples: heat when it turns water into steam, light when it illumines a room, magnetism when a knife-blade attracts a needle. A *chemical force* is one that produces a chemical change. Example: affinity when it converts sand and soda into glass.

One kind of force sometimes develops another. Examples: heat turns sugar into charcoal and steam, light causes chemical changes in vegetation, chemical force corrodes zinc and thus sets free electricity.

6. Physical and Chemical Properties.—A *physical property* is one that can exist in a substance without essentially changing the molecular structure of that or of any other substance. Examples: melting point, color, weight. A *chemical property* is one that determines the character of the chemical change of which a substance is susceptible, or the chemical effect it may exert upon other substances. Examples: the power of gunpowder to explode, the tendency of wood to unite with the oxygen of the air and so decay, the reciprocal action of soda and cream of tartar to cause effervescence.

7. Physics and Chemistry.—The former treats of phenomena in which there is a physical change in matter; the latter, of those in which there is a chemical change. The unit of the physicist is the molecule; of the chemist, the atom. As both kinds of force and properties reside in every substance, and every substance is susceptible of both kinds of change, the two subjects are intimately connected.

PRACTICAL QUESTIONS.—Name some specific property of coal; ink; chalk; grass; tobacco; snow. My knife-blade is magnetized, so that it will pick up a needle; is that a physical or chemical change? Is it treated in Physics or Chemistry? Is the burning of coal a physical or chemical change? The production of steam? The formation of dew? The falling of a stone? The growth of a tree? The flying of a kite? The chopping of wood? The explosion of powder? The boiling of water? The melting of iron? The drying of clothes? The freezing of water? The dissolving of sugar? The forging a nail? The making of bread? The sprouting of a seed? The decay of vegetables? The condensation of steam?

II. GENERAL PROPERTIES OF MATTER.

The principal general properties of matter are magnitude, impenetrability, divisibility, porosity, inertia, and indestructibility.* We cannot imagine a body which does not possess them all.

1. Magnitude is the property of occupying space or having volume. Size is the quantity of space a body fills. A body has three dimensions—length, breadth, and thickness. To measure these, some standard is required. England and the United States have chosen an arbitrary one called the yard. France has adopted the metre, which is about $\frac{1}{40000000}$ of an entire meridian of the earth. This is a

* The first two of these, serving to define matter, are its essential attributes.

unit on which is based a decimal system that, because of its simplicity, is steadily growing in favor.

2. Impenetrability is the property of so occupying space as to exclude all other matter.* No two bodies can occupy the same space at the same time. A book lies upon the table before me; no human power is able to place another in the same spot, until the first book is removed. I attempt to fill a bottle through a closely-fitting funnel; but before the liquid can run in, the air must gurgle out, or the water will trickle down the outside of the bottle.

3. Divisibility is that property which allows a body to be separated into parts. The extent to which the divisibility of matter may be carried is almost incredible.† Example: a grain of strychnine will flavor 1,750,000 grains of water; hence there will be in each grain of the liquid only $\frac{1}{1750000}$ of a grain of strychnine, yet this amount can be distinctly tasted.

4. Porosity is the property of having pores. By this is meant not only the *sensible* pores to which we refer when in common language we speak of a porous body, as bread, wood, unglazed pottery, a sponge, etc., but also the finer or *physical* pores. The latter are as invisible to the eye as the

* In common language, we say a needle penetrates cloth, a nail enters wood, etc.; but a moment's examination shows that they merely push aside the fibres of the cloth or wood, and so press them closer together. With care we can drop a quarter of a pound of shingle-nails into a tumbler brimfull of water, without causing it to overflow. The surface of the water, however, becomes convex.

† Newton estimated that the film of a soap-bubble at the instant of breaking is less than $\frac{1}{2600000}$ of an inch thick. Pure water will acquire the requisite viscidity for making bubbles by adding only $\frac{1}{100}$ part of soap. It is evident that there must be at least one molecule of soap in every cubic $\frac{1}{2600000}$ of an inch of the film, and that the molecule must be smaller than one-hundredth of a cubic $\frac{1}{2600000}$ of an inch, *i. e.*, than $\frac{1}{1757600}$ trillionths of a cubic inch. Now a molecule of soft-soap (if it is a pure potassium stearate, *Chemistry*, p. 219) contains 56 atoms, and this point must be reached before we come to the possible limit of divisibility.—Some idea of the vastness expressed by the word trillion may be derived from the estimate that if Adam, at his creation, had commenced to count one every second of time, he would not yet have completed the first quarter of a trillion; and if Eve had come to his relief, and they had counted day and night, they would not see the end of their task for 10,000 years to come. (See also note on electric sparks, p. 226.)

atoms themselves, and are caused by the fact that the molecules of which a body is composed are not in actual contact, but are separated by minute spaces.* Ex.: to a bowl-full of water it is easy to add a quantity of fine salt without the liquid running over. Only care must be taken to drop in the salt slowly, giving time for it to dissolve and the bubbles of air to pass off. When the water has taken up all the salt it will, we can still add other soluble solids.†—In testing large cannon by hydrostatic pressure (p. 85), water is forced into the gun until it oozes through the thick metal and covers the outside of the gun like froth, then gathers in drops and runs to the ground in streams.‡

Fig. 2.

The process of filtering, so much employed by druggists, depends upon this property; the liquid slowly passes through the pores of the filter, leaving the solid portions behind.—Water, in Nature, is thus purified by percolating through beds of sand and

* These spaces are so small that they cannot be discerned with the most powerful microscope, yet it is thought that they are very large when compared with the size of the atoms themselves. If we imagine a being small enough to live on one of the atoms near the centre of a stone, as we live on the earth, then we are to suppose that he would see the nearest atoms at great distances from him, as we see the moon and stars, and might perchance have need of a fairy telescope to examine them, as we investigate the heavenly bodies.

† In this case we suppose that the particles of salt are smaller than those of water, and those of the different substances used are smaller than those of salt. The particles of salt fill the spaces between the particles of water, and the others occupy the still smaller spaces left between the particles of salt. We may better understand this if we suppose a bowl filled with oranges. It will hold a quantity of peas, then of gravel, then of fine sand, and lastly some water.

‡ In the course of some experiments performed during the 18th century at the Florence Academy, Italy, hollow globes of silver were filled with water and placed in a screw-press. The spheres being flattened, their size was diminished, and the water oozed through the pores of the metal. The philosophers of the day thought this to show that water is incompressible. We now see that it proved only that silver has pores larger than the molecules of water.

gravel.—Cisterns for filtering water have a brick partition in the middle. The water is cleansed as it soaks through the porous brick. Small filters are frequently made of a cask nearly filled with gravel and charcoal; the water is poured in a little reservoir at the top and drawn off at the bottom by a faucet.

5. Inertia is the *negative* property of passiveness.* Matter has no power of putting itself in motion when at rest, nor of coming to rest when in motion. A body will never change its place unless moved, and if once started will move forever unless stopped. Ex.: If we leave the room, and on our return find a book missing, we know some one has taken it—the book could not have gone off of itself.

6. Indestructibility is the property which renders matter incapable of being destroyed. No particle of matter can be annihilated, except by God, its creator. We may change its form, but we cannot deprive it of existence. Ex.: We cut down a tree, saw it into boards, and build a house. The house burns, and only little heaps of ashes remain. Yet in the ashes, and in the smoke of the burning building, exist the identical atoms, which have passed through these various forms unchanged.†

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* The common idea of inertia is that matter actively resists any change; and that when we lift a heavy stone, for example, we must overcome the determined opposition of the body to be moved. Matter possesses no such property. The seeming obstinacy is due to the fact that time is required to impart motion to a body at rest, and to overcome the momentum of a body in motion. The illustrations ordinarily given of inertia are really examples of a law of motion. We are also accustomed to think a body is more inclined to rest than to motion; and so, while we see how a stone could not throw itself, we find it difficult to understand how, once thrown, it does not stop itself. We shall see hereafter that several forces destroy its motion and bring it to rest. (See pp. 28, 29, and Questions 55-62, p. 39.)

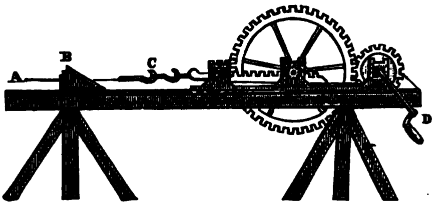
† Walter Raleigh, while smoking in the presence of Queen Elizabeth, offered to bet her majesty that he could tell the weight of the smoke that curled upward from his pipe. The wager was accepted. Raleigh quietly finished, and then weighing the ashes, subtracted this amount from the weight of the tobacco he had placed in the pipe, thus finding the weight of the smoke. When we reach the subject of combustion in chemistry, we shall be able to detect Raleigh's mistake. The smoke and the ashes really weighed more than the original tobacco, since the oxygen of the air had combined with the tobacco in burning.

III. SPECIFIC PROPERTIES OF MATTER.

Among the most important specific properties of matter are ductility, malleability, tenacity, elasticity, hardness, and brittleness.

1. Ductility.—A ductile body is one which can be drawn into wire. Fig. 3 represents a machine for making wire. B is a steel drawing-plate pierced with a series of gradually diminishing holes. A rod of iron, A, is hammered at the end so as to pass through the largest. It is then grasped by a pair of pincers, C, and, by turning the crank D, is drawn through the plate, diminished in diameter and proportionately increased in length. The tenacity of the metal is greatly improved by the process of drawing, so that a cable of fine wire is stronger than a chain or bar of the same weight. Gold, silver, and platinum are the most ductile metals. A silver rod an inch thick, covered with gold-leaf, may be drawn to the fineness of a hair and yet retain a perfect coating of gold, 3 oz. of the latter metal making 100 miles of the gilt-thread used in embroidery. Platinum wire has been drawn so fine that, though it is nearly three times as heavy as iron, a mile's length weighed only a single grain. (*Chemistry*, p. 170.)

FIG. 3.



2. Malleability.—A malleable body is one which can be hammered or rolled into sheets. Ex.: Gold may be beaten until it is only $\frac{1}{360000}$ of an inch thick. It would require

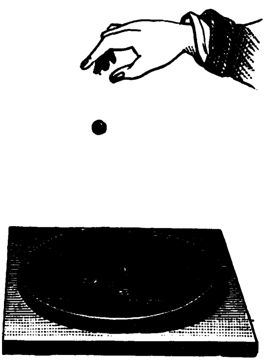
1800 such leaves to equal the thickness of common printing-paper.* Copper is so malleable, that a workman can hammer out a kettle from a solid block.

3. Tenacity.—A tenacious body is one which cannot easily be pulled apart. Iron possesses this quality in a remarkable degree. Steel wire will sustain the weight of about 7½ miles of itself.

4. Elasticity is of four kinds, according as a body tends to resume its original form when *compressed, extended, twisted,* or *bent.*

(1.) ELASTICITY OF COMPRESSION.—Many *solids,* as iron, glass, and caoutchouc, are highly elastic. Ex.: Spread a thin coat of oil on a smooth marble slab. If an ivory ball be dropped upon it, the size of the impression will vary with the distance at which the ball is held above the table. This shows that the ivory is flattened, somewhat like a soap-bubble when it strikes a smooth surface and rebounds.

FIG. 4.



Liquids are condensed with great difficulty, so that for a long time they were considered incompressible. When the force is removed, they regain their exact volume, and are therefore perfectly elastic.

Gases are easily compressed, and are also perfectly elastic. A pressure of 15 lbs. to the square inch reduces the bulk of

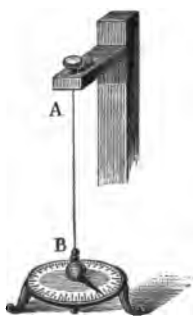
* An ingot of gold is passed many times between steel rollers, which are so adjusted as to be constantly brought nearer together. The metal is thus reduced to a ribbon about $\frac{1}{800}$ of an inch thick. This is cut into inch squares, 150 of which are piled up alternately with leaves of strong paper four inches square. A workman with a 16-lb. hammer beats the pile until the gold is spread to the size of the leaves. Each piece is next quartered, and the 600 squares are placed between leaves of goldbeaters' skin and pounded. They are then taken out, spread by the breath, cut, and the 2,400 squares pounded as before. They are finally trimmed and placed between tissue-paper in little books, each of which contains 25 gold leaves.

water only $\frac{1}{20000}$, whereas it diminishes the volume of a gas $\frac{1}{2}$. A gas may be kept compressed for years, but on being released will instantly return to its original form.

(2.) ELASTICITY OF EXPANSION is possessed largely by solids, slightly by liquids, and not at all by gases. Ex.: India-rubber, when stretched, tends to fly back to its original dimensions. A drop of water hanging to the nozzle of a bottle may be touched by a piece of glass and drawn out to considerable length, but when let go it will resume its spherical form. Gases when extended manifest no tendency to return to their former shape.

(3.) ELASTICITY OF TORSION is the tendency of a thread or wire which has been twisted, to untwist again. It is a delicate test of the strength of a force (Fig. 5).

FIG. 5.



(4.) ELASTICITY OF FLEXURE is the property ordinarily meant by the term elastic. Many solids possess this quality, within certain limits, to a high degree. Swords have been made which could be bent into a circle without breaking. Watch-springs, bows, cushions, etc., are useful because of their elasticity.

5. Hardness.—One body is harder than another when it will scratch or indent it. This property does not depend on density.* Ex.: Gold is about $2\frac{1}{2}$ times denser than iron, yet it is much softer.—Mercury is a liquid, yet it is almost twice as dense as steel.—The diamond is the hardest-known substance, yet it is not one-third as heavy as lead.

6. Brittleness.—A brittle body is one that is easily broken. This property is a frequent characteristic of hard bodies. Ex.: Glass will scratch pure iron, yet it is extremely brittle.

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* A *dense* body has its molecules closely compacted. The word *rare*, the opposite of dense, is applied to gases. *Mass*, or the quantity of matter a body contains, should be distinguished from weight or size (notes, pp. 53, 257).

SUMMARY.

Matter is that which occupies space. A separate portion is called a body, and a particular kind a substance. A general property of matter belongs to all substances, and a specific one to particular kinds. Matter is composed of very minute atoms. A group of atoms forms a molecule, in which reside the specific properties of a substance. A physical change never affects the molecule, but a chemical change breaks it up, and so forms a new substance. Philosophy deals with physical forces and changes; Chemistry with chemical force or attraction, and chemical changes. Magnitude, impenetrability, divisibility, porosity, inertia, and indestructibility are the principal general properties of matter. Magnitude or extension is the property of occupying space; the amount of space a body fills is its size. Impenetrability prevents two bodies from occupying the same space in the same time. Divisibility permits a body, so far as we know, to be divided infinitely. Porosity is of two kinds: sensible and insensible. Sensible pores are caused by the particular structure of a body; insensible pores are inherent in the constitution of a body which consists of molecules that do not touch. Inertia is the natural laziness of matter, which forbids its changing its state from motion to rest, or *vice versa*. Indestructibility prohibits the extinction of matter by man. Ductility, malleability, tenacity, elasticity, hardness, and brittleness are the principal specific properties of matter. A ductile body can be drawn into wire; gold, silver, and platinum are the most noted for this property. A malleable body can be hammered into sheets; gold possesses this quality in a remarkable degree. A tenacious body resists pulling apart; iron is the best example. An elastic body permits a play of its particles, so that they return to their original position when the disturbing force is removed. A hard body cannot easily be indented. A brittle body is readily broken.

HISTORICAL SKETCH.

In ancient times, any seeker after truth was termed a philosopher (a lover of wisdom), and philosophy included all investigations concerning both mind and matter. In the fourth century B. C., Plato assumed that there are two principles, matter and form, which by combining produce the five elements, earth, air, fire, water, and ether. Aristotle, his pupil, established the first philosophical ideas concerning matter

and space. But the method of study generally pursued for 2000 years was one of pure metaphysical speculation. Observation had no place, but the philosophers made up a theory, and then accommodated facts to it. They guessed about the real essence of things, as to whether matter exists except when perceived by the mind,* and how a change in matter can produce a change in mind. In 1620, Bacon published his "Novum Organum," advocating the inductive method of studying nature. He argued that the philosopher should seek to benefit mankind, and that, instead of wasting his time in sterile and ingenious theories about the world and matter, he should watch the phenomena of life, gather facts, and then reasoning from effects back to their causes, reach the general law. This work is commonly said to have established the modern method of investigation. Ptolemy, Archimedes, Galileo, and other physicists, however, had long before proved its value.

The Atomic Theory was propounded by Democritus, in the fifth century B. C., and twenty-two centuries later elaborated by Dalton, an English physicist. The grander generalization and development of this law was advanced in 1811 by Avogadro, an Italian, and afterward extended by the French philosopher, Ampère. The latter asserted that "equal volumes of all substances, when in the gaseous form and under like conditions, contain the same number of molecules." For half a century this view lay dormant. Of late it has borne fruit, and the molecular theory has become to Chemistry what the law of gravitation is to Astronomy. The labors of Thomson, Cooke, Tait and others are now building up the whole superstructure of Chemistry and Physics upon this basis.

The history of the establishment of a standard of measures is a curious one. Anciently, length was referred to some portion of the human body, as the foot; the cubit (the length of the forearm from the elbow to the end of the middle finger); the finger's length or breadth; the hand's breadth; the span, etc. In England, Henry I. (1120) ordered that the ell, the ancient yard, should be the exact length of his arm. Afterward a standard yard-stick was kept at the Exchequer in London; but it was so inaccurate, that a commissioner, who examined it in 1742, wrote: "A kitchen poker filed at both ends would make as good a standard. It has been broken, and then repaired so clumsily that the joint is nearly as loose as a pair of tongs." In 1760, Mr. Bird carefully prepared a copy of this for the use of the Government. It was not legally adopted until 1824, when it was ordered that if destroyed, it

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* Dr. Johnson once remarked to a gentleman who had been defending the theory that there is no external world, as he was going away, "Pray, sir, don't leave us, for we may perhaps forget to think of you, and then you will cease to exist."

should be restored by a comparison with the length of a pendulum vibrating seconds at the latitude of London. (Third law, p. 60.) At the great fire in London, 1834, the Parliament House was burned, and with it Bird's yard-stick. Repeated attempts were then made to find the length of the lost standard by means of the pendulum. This was found impracticable, on account of errors in the original directions. At last the British government adopted a standard prepared from the most reliable copies of Bird's yard-stick. A copy of this was taken by Troughton, a celebrated instrument-maker of London, for the use of our Coast Survey.*

The French had previously adopted for the length of the legal foot that of the royal foot of Louis XIV., as perishable a standard as Henry's arm. When they had established the metric system, they found that a mistake had been made in measuring the meridian. The English scientists discovered a difficulty in the calculation from the pendulum. So that both these attempts to fix upon an absolute unit in Nature have failed, and the French and English systems are alike founded upon arbitrary standards.

Consult Cooke's "New Chemistry," chapter on Molecules, etc.; Powell's "History of Natural Philosophy"; Buckley's "History of Natural Science"; Whewell's "History of the Inductive Sciences"; Roscoe's "John Dalton and his Atomic Theory," in Manchester Science Lectures, '73–4; "Appleton's Cyclopædia," Art. Molecules; Outerbridge's "Divisibility of Gold and Other Metals," in Popular Science Monthly, Vol. XI, p. 74; Cooke's "The Radiometer—a fresh evidence of a Molecular Universe," Popular Science Monthly, Vol. XIII, p. 1; Tait's "Recent Advances in Physical Science," Chap. XII, The Structure of Matter: Hoefer, "Histoire de la Physique et de la Chimie"; Draper's "History of Intellectual Development."

* This yard is about $\frac{1}{1000}$ of an inch longer than the British standard. According to Act of Congress, sets of weights and measures have been distributed to the governors of the several States. The yards so furnished are equal to that of the Troughton scale. We have no national standard established by law.

II.

Motion and Force.

Rest is nowhere. The winds that come and go, the ocean that uneasily throbs along the shore, the earth that flies about the sun, the light that darts through space—all tell of a universal law of Nature. The solidest body hides within it inconceivable velocities. Even the molecules of granite and iron have their orbits as do the stars, and revolve as ceaselessly.

No energy is ever lost. It changes its form, but the eye of philosophy detects it and enables us to drive it from its hiding-place undiminished. It assumes Protean guises, but is everywhere a unit. It may disappear from the earth; still—

> "*Somewhere yet that atom's force*
> *Moves the light-poised universe.*"

ANALYSIS.

MOTION AND FORCE.

1. DEFINITIONS.
2. RESISTANCES TO MOTION.
   - (1.) **Friction.**
   - (2.) **Resistance of air and water.**
3. MOMENTUM.
4. COMMUNICATION OF MOTION.
5. THREE LAWS OF MOTION.
6. COMPOUND MOTION.
7. COMPOSITION OF FORCES.
8. RESOLUTION OF FORCES.
9. MOTION IN A CURVE.
10. CIRCULAR MOTION.
11. THE GYROSCOPE.
12. REFLECTED MOTION.
13. ENERGY.
14. POTENTIAL AND DYNAMIC ENERGY.
15. CONSERVATION OF ENERGY.

MOTION AND FORCE.

1. Motion is a change of place. All motion, as well as rest, with which we are acquainted, is relative. Ex.: When we ride in the cars, we judge of our motion by the objects around us.—A man on a steamer may be in motion with regard to the shore, but at rest with reference to the objects on the deck of the vessel. *Force* is that which produces or tends to produce or to destroy motion. *Velocity* is the rate at which a body moves.

2. The Resistances to Motion are friction and the resistance of air and water. (1.) Friction is the resistance caused by the surface over which a body moves. It is of great value in common life. Without it, nails, screws, and strings would be useless; engines could not draw the cars; we could hold nothing in our hands; and we should everywhere walk as on glassy ice. (2.) The resistance which a body meets in passing through air or water is caused by the particles displaced. It increases according to the square of the velocity.* Thus, if in running we double our speed, we displace twice as much air in the same time, and give to each particle twice the velocity; hence the resistance will be quadrupled.

3. Momentum is the quantity of motion in a body. It is the weight of the body multiplied by its velocity per second, expressed in feet. Ex.: A stone weighing 5 lbs., thrown with a velocity of 20 feet per second, has a momentum of 100.†

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* This is true only at a moderate velocity, for at a high speed some of the medium is carried along with the body, and the resistance increases much faster than according to v^2.

† A heavy body may be moving very slowly and yet have an immense momentum. Ex.: An iceberg, with a scarcely perceptible motion, will crush the strongest man-of-war as if it were an egg-shell.—Vessels lying at a wharf grind against one another

4. The Communication of Motion is not instantaneous.* If I press with all my might against a rock weighing a ton, I fail to move it, press I ever so long. The force is not sufficient to overcome the friction between the rock and the ground. If, however, we could conceive the rock poised in empty space, the least touch would at once move it with a velocity proportional to $\frac{\text{pressure}}{\text{mass}}$. If I strike one end of a rail a mile long, the tremor will take a definite time to reach the other end. If, on the other hand, a powerful engine suddenly pulls at one end of the rail, so as to draw it over a considerable distance in a second, I can imagine that the other end will move after an almost infinitely short time; but if the engine drag the rail continuously, both ends will have the same velocity, and the whole rail will move together.

5. Three Laws of Motion.—FIRST. *A body set in motion will move forever in a straight line, unless acted on by some external force.* This is only another statement of the passiveness of matter, or the property of inertia. Obviously, no experiment will directly prove the law. There is a curious illustration, however, in the swinging of a pendulum under the receiver of an air-pump. The more perfectly the air is exhausted, the longer it will vibrate. In the best vacuum we can produce, it will swing for twenty-four hours. It is supposed that if all "resistances to motion" were removed, the pendulum would never stop.

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with prodigious force, by the slow movement of the tide.—Soldiers have thought to stop a spent cannon-ball by putting a foot against it, but have found its momentum sufficient to break a leg.

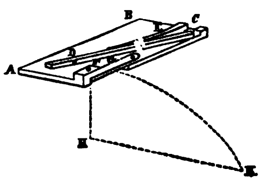
On the other hand, a light body moving with a high velocity may have an enormous momentum. Ex.: The air in a hurricane will tear up trees by the roots and level buildings to the ground.—Sand driven from a tube by steam is used for drilling and in stone-cutting, engraving, etc.

* A stone thrown against a pane of glass shatters it; but a bullet fired through it will make only a round hole. The bullet is gone before the motion has time to pass into the surrounding particles.—A fraction of time is required for a ball to receive the force of exploding powder and to get under full headway. An instrument is used to determine the acceleration of speed before leaving the gun.

To this law are to be referred many ordinary illustrations of the so-called "inertia of matter." Thus, when we endeavor to stop a moving body, as a wagon, we must overcome its momentum. The danger in jumping from a car in rapid motion lies in the fact that the body has the speed of the train, while the forward motion of the feet is checked by the contact with the ground.*

SECOND LAW.—*A force acting upon a body in motion or at rest, produces the same effect whether it acts alone or with other forces.* Ex.: All bodies upon the earth are in constant motion with it, yet we act with the same ease that we should were the earth at rest.†—We throw a stone directly at an object and hit it, yet, within the second, the mark has gone forward many feet.‡—If a cannon-ball be thrown horizontally, it will fall as fast and strike the earth as soon as if dropped to the ground from the muzzle of the gun. In Fig. 6, D is an arm driven by a wooden spring, E, and turning on a hinge at C. At D is a hollow containing a bullet, so placed that when the arm is sprung, the ball will be thrown in the line FK. At F is a

FIG. 6.



* Some jump as nearly as possible in the direction in which the train is moving, and are ready to run the instant their feet touch the ground. Then with all their strength they gradually overcome the inertia of the body, and after a few rods can turn as they please. Others jump backward from the train with sufficient force to overcome their forward motion, and so drop directly downward.

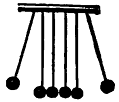
† A ball thrown up into the air with a force that would cause it to rise 50 feet, will ascend to that height whatever horizontal wind may be blowing.—While riding on a car, we throw a stone at some object at rest. The stone, having the motion of the train, strikes just as far ahead of the object as it would have gone had it remained on the train. In order to hit the mark, we should have aimed a little back of it.—The circus-rider wishes, while his horse is at full speed, to jump through a hoop suspended before him. He simply springs directly upward. Going forward by the momentum which he had acquired before he leaped from the horse, he passes through the hoop and alights upon the saddle again.—A person riding in a coach drops a cent to the floor. It apparently strikes where it would if the coach were at rest.

‡ The earth moves in its orbit around the sun at the rate of about 18 miles per second. See *Fourteen Weeks in Astronomy*, p. 106.

similar ball, supported by a thin slat, G, and so arranged that the same blow which throws the ball D, will let the ball F fall in the line FH. The two balls will strike the floor at the same instant.

THIRD LAW.—*Action is equal to reaction, and in the contrary direction.* Ex.: A bird in flying beats the air downward, but the air reacts and supports the bird.—The powder in a gun explodes with equal force in every direction, driving the gun backward and the ball forward, with the same momentum. Their velocities vary with their weights; the heavier the gun, the less will the recoil be noticed.—When we spring from a boat, unless we are cautious, the reaction will drive it from the shore.—When we jump from the ground, we push the earth from us, while it reacts and pushes us from it; we separate from each other with equal momentum, and our velocity is as much greater than that of the earth as we are lighter.—We walk by reason of the reaction of the ground on which we tread. Thus at every step we move the earth.

FIG. 7.



The apparatus shown in Fig. 7 consists of ivory balls hung so as readily to vibrate.* If a ball be let fall from one side, it will strike the second ball, which will react with an equal force, and stop the motion of the first, but transmit the motion to the third; this will act in the same manner, and so on through the series, each acting and reacting until the last ball is reached; this will react and then bound off, rising as high as the first ball fell (except the loss caused by resistances to motion). If two balls be raised, two will fly off at the opposite end; if two be let fall from one side and one from the other, they will respond alternately.

6. Compound Motion.—Let a ball at A (Fig. 8) be acted on by a force which would drive it in a given time to

* The same experiments can be performed by means of glass marbles or billiard balls placed in a groove. Better still, attach strings to glass marbles by means of mucilage and bits of paper and suspend them from a simple wooden frame.

B, and also at the same instant by another which would drive it to D in the same time; the ball will move in the direction AC. Ex.: A person wishes to row a boat across a swift current which would carry him down stream. He therefore steers toward a point above that which he wishes to reach, and so goes directly across.—A bird, beating the air with both its wings, flies in a direction different from that which would be given by either one.

FIG. 8.

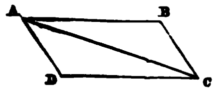
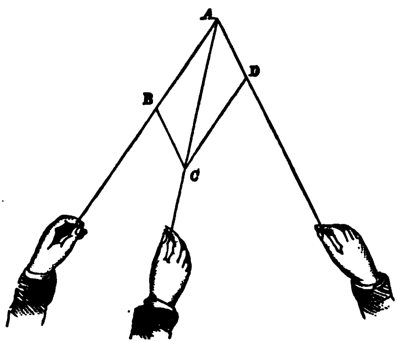


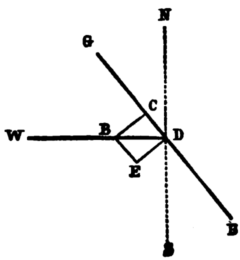
FIG. 9.



7. Composition of Forces.—When a body is thus acted on by two forces, we draw lines representing their directions, and mark off AD and AB, whose lengths represent their comparative magnitudes. We next complete the parallelogram and draw the diagonal AC, which denotes the *resultant* of these forces, and gives the direction in which the body will move. If more than two forces act, we find the resultant of two, then of that resultant and a third force, and so on.

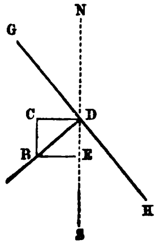
8. Resolution of Forces consists in finding what two forces are equivalent to a given force. A parallelogram is drawn having the given force as a diagonal. Ex.: There is a wind blowing from the west against GH (Fig. 10), the sail of a vessel going north. We can resolve the

FIG. 10.



wind-force BD into the two forces BE and BC. The former, blowing parallel to the sail, is of no use; the latter is perpendicular to it, and drives the vessel northeast. Again, resolving BD in Fig. 11, which represents the vertical force BC in Fig. 10, we find that it is equivalent to two forces BE and BC. The former pushes the vessel sideways, but is mainly counteracted by the shape of the keel and the action of the rudder. The latter is parallel to the course of the ship, and hurries it north.

Fig. 11.



By shifting the rigging, one vessel will sail into harbor while another is sailing out, both driven by the same wind.* Figs. 12 and 13 show how, by twice resolving the force of the wind from the W., as in the last figures, when the sail GH is placed in the new position, we have (Fig. 13) a force BC, which drives the vessel S.† If a vessel

Fig. 12.

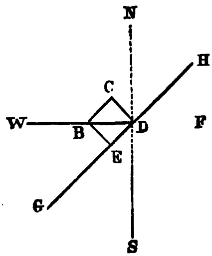
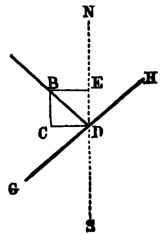


Fig. 13.



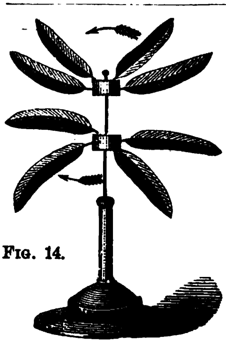


Fig. 14.

* The toy shown in Fig. 14, and easily made by any pupil, proves how a change in the position of the sails will produce a contrary effect. Carry this wind-mill forward, and the two sets of feather-vanes will revolve swiftly in opposite directions.

† In a similar manner we may resolve the three forces which act upon a kite—viz., the pull of the string, the force of the wind, and its own weight. In Fig. 12, let GH represent the face of the kite. We can resolve BD, the force of the wind, into BC and BE. We next resolve BD, in Fig. 13, which corresponds to BC in Fig. 12, into BE and BC. We then have a force, BC, which overcomes the weight of the kite and also tends to lift it upward. The string pulls in the direction BD, perpendicularly to the face. The kite obeys neither one of these forces, but both, and so ascends in a direction GD, between the two. It is really drawn up an inclined plane by the joint force of the wind and the string.

were to be sailed due W. against the wind, it would *tack* alternately NW. and SW. In this way it could go almost in the "teeth of the wind."

A canal-boat drawn by horses is acted upon by a force which tends to bring it to the bank. This force may be resolved into two, one pulling toward the tow-path, and the other directly ahead. The former is counteracted by the shape of the boat and the action of the rudder; the latter draws the boat forward.

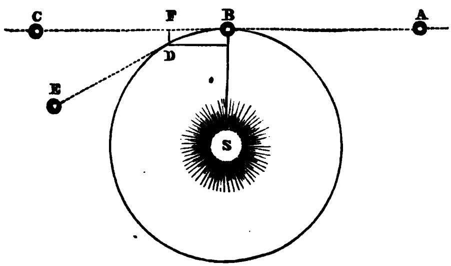
9. Motion in a Curve.—Whenever two or more instantaneous forces act upon a body, the path is a straight line. When one is instantaneous and the other continuous, it is a curved line. Ex.: When a body is thrown into the air, except in a vertical line (p. 54), it is acted upon by the instantaneous force of projection and the continuous force of gravity, and so describes a line which curves toward the earth.

10. Circular Motion is produced when a moving body is drawn toward a centre by a constant force. Thus, when a sling is whirled, the stone is pulled toward the hand by the string, and as, according to the third law of motion, every action has its equal and opposite reaction, the hand is pulled toward the stone. If the string break, the stone will continue to move, according to the first law of motion, in a straight line in the direction of a tangent to the circle at that point. The tension of the string, acting inward, is called the *Centripetal* (*centrum*, the centre, *petere*, to seek) force; and the reaction of the stone upon the string, acting outward, is termed the *Centrifugal* (*centrum*, the centre, *fugere*, to flee) force.*

* It should be noticed that in circular motion there is but one true force concerned. It acts, however, upon a body in motion. The so-called centrifugal force has nothing to do with the production of the motion, being merely the resistance which the body offers by its inertia to the operation of the centripetal force, and ceases the instant that force is discontinued. It does not act at right angles to the centripetal force, as is often stated, but in direct opposition. A body never flies off from the centre impelled by the centrifugal force, since that can never exceed the centripetal (action = reaction), and moreover the path of such a body is in the direction of a tangent, and

The following examples are among those usually given to illustrate the action of the centre-fleeing force: Water flies from a grindstone on account of the centrifugal force produced in the rapid revolution, which overcomes the *adhesion.*—In factories, grindstones are sometimes revolved with such velocity that this force overcomes that of *cohesion,* and the ponderous stones fly into fragments.—A pail full of water may be whirled around so rapidly that none will spill out, because the centrifugal force overcomes that of *gravity.*—When a horse is running around a small circle, he bends inward to overcome the centrifugal force.

FIG. 15.

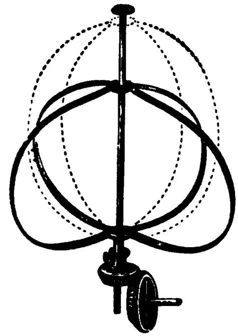


The heavenly bodies present the grandest example of circular motion. We may suppose the earth to have been moving originally in the direction AC. The attraction of the sun, however, drawing it in the direction BS, it passes along the line BD. If the centripetal force were suddenly to cease, the earth would fly off into space along a tangent, as BC. The rapid revolution of the earth on its axis tends to throw off all bodies headlong. As this acts in opposition to gravity, it diminishes the weight

not the radius of a circle. Thus, when water is thrown off a grindstone in rapid rotation, the tendency of the water to continue to move on in the direction of the straight line in which it is going at each instant (in other words, the inertia of the water) overcomes its adhesion to the stone, and it flies off in obedience to the first law of motion. So, also, when a grindstone driven at a high speed, breaks, and the fragments are thrown with great velocity, we are not to suppose that the centrifugal force impels them through the air. That force existed only while the stone was entire. It was opposed to the force of cohesion, and in the moment of its triumph ceased, and the fragments of the stone fly off in virtue of the velocity they possess at that instant. Again, the so-called centrifugal force is not a real force urging bodies upward at the equator. The earth's surface is merely falling away from a tangent, and a part of the force of gravity is spent in overcoming the inertia of bodies. The term centrifugal force has caused much confusion, and will doubtless soon be discarded.

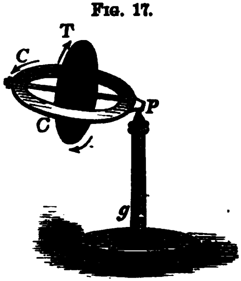
of bodies at the equator, where it is greatest, $\frac{1}{289}$. It also tends to drive the water on the earth from the poles toward the equator. Were the velocity of the earth's rotation to diminish, the water would run back toward the poles, and tend to restore the earth to a spherical form. This influence is well illustrated by the apparatus shown in Fig. 16. The hoop is made to slide upon its axis, and if revolved rapidly it will assume an oval form, bulging out more and more as the velocity is increased.*

FIG. 16.



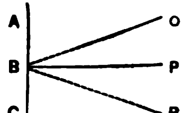
11. The Gyroscope beautifully illustrates the principle of the composition of forces in rotary motion. In Fig. 17 a wheel revolves within a ring which is sustained at one end by an upright support. If the wheel is made to revolve swiftly by unwinding a string, and then placed on the support, instead of falling, as one would suppose, the whole begins to revolve rapidly around the point of support, in a resultant between the force of gravity and the rotary motion of the wheel. If we attempt to raise or lower the ring, it will sensibly oppose the change and persist in its plane of rotation.

FIG. 17.



12. Reflected Motion is produced by the reaction of a surface against which an elastic body is cast. If a ball be thrown

FIG. 18.



* This apparatus is accompanied by objects to illustrate the principle that all bodies tend to revolve about their shortest diameters, an assurance that the earth will never change its axis of rotation while it retains its present form. "Tie to

in the direction OB against the surface AC, it will rebound in the line BR. The angle OBP, that of *incidence*, = the angle PBR, that of *reflection*.

13. Energy is the power of doing work, *i. e.*, of overcoming any kind of resistance. It is in general something put into a body by means of work, and which comes out of it when it does work. Ex.: A wound-up clock, a red-hot iron. The difference between energy and momentum is evident. When a bullet is fired from a rifle, the momenta of both are equal, but the energy of the former, *i. e.*, its power of doing work, as piercing a board, is far greater. Energy is proportional to the square of the velocity. Thus, a cannon-ball given double speed will penetrate four times as far into a wall; and a stone thrown upward at the rate of 96 feet per second will rise 9 times as far as with a velocity of 32 feet (p. 55).

14. Two Forms of Energy.—Energy may be either active or latent. When a rock is tumbling down a mountain-side, it exhibits the force of gravity in full sway; but when the rock was lodged on the mountain-top, it possessed the same energy, which could be developed at any moment by loosening it from its place. These two forms are known

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the middle of a lead pencil a piece of string about three feet long. Suspend so that the pencil will balance itself. Now twist the end of the string between the thumb and the first finger of the right hand, steadying and holding the string with the left hand. A circular motion will thus be communicated to the pencil, and it will revolve around the point on which it is suspended. Tie a piece of white string around the middle of the pencil, or its centre of gravity, simply to show the position of that point. Now tie the first piece of string half-way between the end of the pencil and the centre of gravity, and communicate the circular motion described above, and we shall observe that the pencil will still revolve around the centre of gravity, the point marked by the white string being at rest. It can thus be shown that anything, of whatever shape, will tend to revolve on its shortest diameter. If the end links of a small steel chain (such as is often attached to purses or parasols) be hooked together, the string tied to a link, and the circular motion given, it will be observed that the chain begins to take an elliptical form, which gradually approaches that of a circle, until at last it becomes a circle, when it revolves horizontally. This shows that even a ring is subject to the same law—that is, revolves on its shortest axis."

as energy of motion and energy of position, or *actual* and *potential* (possible) energy.*

15. Conservation of Energy.—One kind of energy is changed into another without loss. The sum of all the energies in the universe remains the same. A hammer falls by the force of gravity and comes to rest. Its potential energy changes to kinetic and then disappears. Its motion as a mass is converted into one of atoms, and reveals itself to our touch as heat (p. 184).†

PRACTICAL QUESTIONS.—1. Can a rifle-ball be fired through a handkerchief suspended loosely from one corner? 2. A rifle-ball thrown against a board standing edgewise, will knock it down; the same bullet fired at the board will pass through it without disturbing its position. Why is this? 3. Why can a boy skate safely over a piece of thin ice, when, if he should pause, it would break under him directly. 4. Why can a cannon-ball be fired through a door standing ajar, without moving it on its hinges? 5. Why can we drive on the head of a hammer by simply striking the end of the handle? 6. Suppose you were on a train of cars moving at the rate of 30 miles per hour; with what velocity would you be thrown forward if the train were

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* Actual energy is also styled dynamic or kinetic energy, and potential is termed static energy. In mechanics, kinetic energy is called *vis viva* ($= \frac{1}{2}mv^2$), or striking force. We wind a watch, and by a few moments of labor condense in the spring a potential energy, which is doled out for 24 hours in the dynamic energy of the wheels and hands. Draw a violin bow, and the potential energy of the arm is stored up in the stretched cord. Lift a pendulum, and you thereby give the weight potential energy. Let it fall, and the potential changes gradually to dynamic. At the centre of the arc the potential is gone and kinetic is possessed. Then the kinetic changes again to potential, which increases till the end of the arc is reached and the pendulum ceases to rise, when the energy is that of position, not of motion. Potential energy is one that is concealed, lying in wait and ready to burst forth on the instant. It is a loaded gun prepared for the arm of the marksman. It is a river trembling on the brink of a precipice, about to take the fearful leap. It is a weight wound up and held against the tug of gravity. It is the engine on the track with the steam hissing from every crevice. It is the drop of water with a thunderbolt hidden within its crystal walls. On the contrary, dynamic energy is in full view, in actual operation. The bullet is speeding to the mark; the river is tumbling; the weight is falling; the engine is flying over the rails; and the bolt is flashing across the sky. It is heat radiating from our fires; electricity flashing our messages over the continent; and gravity drawing bodies headlong to the earth.

† No energy in nature can be wasted. It must accomplish something. "A blow with a hammer moves the earth. A boy could in time draw the largest ship across the harbor in calm weather."

"Water falling day by day
Wears the hardest rock away."

Statues are worn smooth by the constant kissing of enthusiastic worshippers. Stone steps are hollowed by the friction of many feet. The ocean is filled by small drops which fall from the clouds. We may notice none of these forces singly, but their effects in the aggregate startle us.

stopped instantly? 7. In what line does a stone fall from the masthead of a vessel in motion? 8. If a ball be dropped from a high tower, it will strike the ground a little east of a vertical line. Why is this? 9. It is stated that a suit was once brought by the driver of a light wagon against the owner of a coach for damages caused by a collision. The complaint was "the latter was driving so fast that when the two carriages struck, the driver of the former was thrown forward over the dashboard." On trial he was nonsuited, because his own evidence showed him to be the one who was driving at the unusual speed. Explain. 10. Suppose a train moving at the rate of 30 miles per hour; on the rear platform is a cannon aimed parallel to the track and in a direction precisely opposite to the motion of the car. Let a ball be discharged with the exact speed of the train; where would it fall? 11. Suppose a steamer in rapid motion, and on its deck a man jumping. Can he jump further by leaping the way the boat is moving than in the opposite direction? 12. On which bank of a river running south will the floating *débris* be most likely to accumulate? 13. If a stone be dropped from the masthead of a vessel in motion, will it strike the same spot on the deck that it would if the vessel were at rest? 14. Could a party play ball on the deck of the Great Eastern when steaming along at the rate of 20 miles per hour, without making allowance for the motion of the ship? 15. Since action is equal to reaction, why is it not so dangerous to receive the "kick" of a gun as the force of the bullet? 16. If you were to jump from a carriage in rapid motion, would you leap directly toward the spot on which you wished to alight? 17. If you wished to shoot a bird in swift flight, would you aim directly at it? 18. At what parts of the earth is the centrifugal force least? 19. What causes the mud to fly from the wheels of a carriage in rapid motion? 20. What proof have we that the earth was once a soft mass? 21. On a curve in a railroad, one track is always higher than the other. Why is this? 22. What is the principle of the sling? 23. The mouth of the Mississippi River is about 2½ miles farther from the centre of the earth than its source. In this sense it may be said to "run up hill." What causes this apparent opposition to the attraction of gravity? 24. Is it action or reaction that breaks an egg, when I strike it against the table? 25. Was the man philosophical who said that it "was not the falling so far, but the stopping so quick, that hurt him?" 26. If one person runs against another, which receives the greater blow? 27. Would it vary the effect if the two persons were running in opposite directions? In the same direction? 28. Why can you not fire a rifle-ball around a hill? 29. Why is it that a heavy rifle "kicks" less than a light shot-gun? 30. A man on the deck of a large vessel draws a small boat toward him. How much does the ship move to meet the boat? 31. Suppose a string, fastened at one end, will just support a weight of 25 lbs. at the other. Unfasten it, and let two persons pull upon it in opposite directions. How much can each pull without breaking it? 32. Can a man standing on a platform-scale make himself lighter by lifting up on himself? 33. Why cannot a man lift himself by pulling up on his boot-straps? 34. If, from a gun placed vertically, a ball were fired into perfectly still air, where would it fall? 35. With what momentum would a steamboat weighing 1,000 tons, and moving with a velocity of 10 feet per second, strike against a sunken rock? 36. With what momentum would a train of cars weighing 100 tons, and running 10 miles per hour, strike against an obstacle? 37. What would be the comparative striking force of two hammers, one driven with a velocity of 20 feet per second and the other 10 feet? 38. If a 100 horse-power engine can propel a steamer 5 miles per hour, will one of 200 horse-power double its speed? 39. Why is a bullet flattened if fired obliquely against the surface of water? 40. Why are ships becalmed at sea often floated by strong currents into dangerous localities without the knowledge of the crew? 41. A man in a wagon holds a 50-lb. weight in his hand. Suddenly the wagon falls over a precipice. Will he, while dropping, bear the strain of the weight? 42. Why are we not sensible of the rapid motion of the earth? 43. A feather is dropped from a balloon which is immersed in and swept along by a swift current of air. Will the feather be blown away or will it appear to drop directly

down? 44. Suppose a bomb-shell, flying through the air at the rate of 500 feet per second, explodes into two parts of equal weight, driving one-half forward in the same direction as before, but with double its former velocity. What would become of the other half? 45. Which would have the greater penetrating power, a small cannon-ball with a high velocity, or a large one with a low velocity? 46. There is a story told of a man who erected a huge pair of bellows in the stern of his pleasure-boat, that he might always have a fair wind. On trial, the plan failed. In which direction should he have turned the bellows? 47. If a man and a boy were riding in a wagon, and, on coming to the foot of a hill, the man should take up the boy in his arms, would that help the horse? 48. Why does a bird, as it begins to fly, always, if possible, turn toward the wind? 49. If we whirl a pail of water swiftly around with our hands, why will the water tend to leave the centre of the pail? 50. Why will the foam collect at the hollow in the centre? 51. If two cannon-balls, one weighing 8 lbs. and the other 2 lbs., be fired with the same velocity, which will go the further? 52. Resolve the force of the wind which turns a common wind-mill, and show how one part acts to push the wheel against its support, and one to turn it around. 53. Why is a gun firing blank cartridges more quickly heated than one firing balls? 54. When an animal is jumping or falling, can any exertion made in mid-air change the motion of its centre of gravity? 55. If one is riding rapidly, in which direction will he be thrown when the horse is suddenly stopped? 58. When standing in a boat, why, as it starts, are we thrown backward? 59. When carrying a cup of tea, if we move or stop quickly, why is the liquid liable to spill? 58. Why, when closely pursued, can we escape by dodging? 59. Why is a carriage or sleigh, when sharply turning a corner, liable to tip over? 60. Why, if you place a card on your finger and on top of it a cent, can you snap the card from under the cent, which will then drop on your finger? 61. Why is a "running jump" longer than a "standing jump"? 62. Why, after the sails of a vessel are furled, does it still continue to move? and why, after the sails are spread, does it require some time to get it under full headway? 63. Why can a tallow candle be fired through a board?

SUMMARY.

Matter, so far as we know it, is in constant change. This change of place is termed motion. Terrestrial motion is restricted by friction, by the air, and by water. Friction is caused by the roughness of the surface over which a body moves. It may be decreased by the use of grease to fill up the minute projections, or by changing the sliding into rolling friction. Air and water must be displaced by a moving body, and the resistance they offer is increased, in general, according to the square of its velocity. Motion is governed by three laws; viz.: A moving body left to itself tends to go forever in a straight line; a force has the same effect whether it acts alone or with other forces, and upon a body at rest or in motion; and action is equal and opposed to reaction. By means of the principles of the composition and resolution of forces, we can find the individual effect of a single force or the combined effect of several forces. Motion produced by two or more instantaneous forces is in a straight line; when one is continuous,

the result is a curved line; and when the continuous force, directed toward a fixed point, acts upon a moving body, a circle is then described. A croquet ball struck by two mallets at the same moment, illustrates the first kind of motion; the path of a bullet or rocket in the air exhibits the second; and the movement of a stone whirled in a sling is an example of the third. When a rubber ball bounds back from a surface against which it is thrown, the angle of reflection equals the angle of incidence.

Energy, or the power of doing work, is a general term employed to unify all the forces of nature. Out of it grows the grand law of the Conservation of Energy, which teaches that the different forces are only different forms of one all-pervading energy, and that they are mutually interchangeable, and indestructible as matter itself.

HISTORICAL SKETCH.

Aristotle taught that all motion is naturally circular, and this view was held by his school. He divided the phenomena of motion into two classes—the natural and the violent. As an instance of the former, he gave the falling of a stone, which constantly increases in velocity; and of the latter, a stone thrown vertically up, which being against nature, continually goes slower. Newton, in his "Principia" published in 1687, propounded the laws of motion as now received. Other philosophers, notably Galileo, Hooke, and Huygens, had anticipated much of his reasoning, yet so slowly were his opinions accepted that "at his death," says Voltaire, "he had not more than twenty followers outside of England."

The law of the Conservation of Energy, Faraday, the great English physicist, pronounced "the grandest ever presented for the contemplation of the human mind." It has been established within the present century; yet we now know that former scholars had inklings of the wonderful truth. It arose in connection with discoveries on the subject of Heat, and its history will be treated of hereafter.

Consult Stewart's "Conservation of Energy"; Youmans's "Correlation of the Physical Forces"; Faraday's "Lectures on the Physical Forces"; Everett's "Deschanel's Natural Philosophy"; Tait's "Recent Advances in Physical Science"; Maxwell's "Matter and Motion"; "Appleton's Cyclopædia," Art. Correlation of Forces, Gyroscope, etc.; Tyndall's "Crystalline and Molecular Forces," in Manchester Science Lectures, '73–4; Crane's "Ball Paradox," in Popular Science Monthly, Vol. X, p. 725.

III.

ATTRACTION.

"The smallest dust which floats upon the wind
Bears this strong impress of the Eternal mind:
In mystery round it subtle forces roll,
And gravitation binds and guides the whole."

"*Attraction, as gravitation, is the muscle and tendon of the universe, by which its mass is held together and its huge limbs are wielded. As cohesion and adhesion, it determines the multitude of physical features of its different parts. As chemical or interatomic action, it is the final source to which we trace all material changes.*"—ARNOTT.

ANALYSIS.

- **ATTRACTION.**
  - **I. MOLECULAR FORCES.**
    - —Attractive and Repellent Forces.
    - 1. Cohesion.
      - 1. Definition of Cohesion.
      - 2. Three States of Matter.
      - 3. Cohesion acts at Insensible Distances.
      - 4. Liquids tend to form Spheres.
      - 5. Solids tend to form Crystals.
      - 6. Annealing and Tempering.
      - 7. Rupert's Drop.
    - 2. Adhesion.
      - 1. Definition and Illustration of Adhesion.
      - 2. Capillary Attraction.
        - (1.) *In water.*
        - (2.) *In mercury.*
        - (3.) *Illustrations.*
      - 3. Solution.
      - 4. Diffusion of Liquids.
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  - **II. ATTRACTION OF GRAVITATION.**
    - 1. Law of Gravitation.
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    - 4. Falling Bodies.
      - (1.) *Laws of falling bodies.*
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      - (3.) *To find depth of well.*
      - (4.) *Bodies thrown upward.*
    - 5. Centre of Gravity.
      - (1.) *Three states of equilibrium.*
      - (2.) *To find centre of gravity.*
      - (3.) *General principles.*
      - (4.) *Physiological facts.*
    - 6. The Pendulum.
      - (1.) *Three laws.*
      - (2.) *Centre of oscillation.*
      - (3.) *To find centre of oscillation.*
      - (4.) *As time-keeper.*
      - (5.) *Other uses.*

I. MOLECULAR FORCES.

Attractive and Repellent Forces.—If we take a piece of iron and attempt to pull it to pieces, we find that there is a force which holds the molecules together and resists our efforts. If we try to compress the metal, we find that there is a force which holds the molecules apart and resists our efforts as before. If, however, we apply heat, the iron expands and finally melts. So, also, if we heat a bit of ice, the attractive force is gradually overpowered, the solid becomes a liquid, and at last the repellent force predominates and the liquid passes off in vapor. In turn, we can cool the vapor, and convert it back successively into water and ice. We thus see that there are two opposing forces which reside in the molecules—an attractive and a repellent force, and that the latter is heat. There are three kinds of the former, *cohesion*, *adhesion*, and *chemical affinity.**

1. COHESION.

1. Cohesion is that force which holds together molecules of the same kind.

2. Three States of Matter.—Matter occurs in three states—*solid*, *liquid*, and *gaseous*. These depend on the relation of the attractive and repellent forces, cohesion and heat. If they are nearly balanced, the body is *liquid;* if the attractive force prevail, it is *solid;* if the repellent, it is *gaseous*. Most substances may be made to take the three states successively. Thus, by the addition of heat, ice may be converted into water, and thence into vapor; or *vice*

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* Chemical affinity produces chemical changes, and its consideration belongs to Chemistry. It binds together atoms of different kinds, and produces a compound unlike the original elements.

versa, by the subtraction of heat. Most solids pass easily to the liquid form, others go directly from the solid to the gaseous state.

3. Cohesion Acts at Insensible Distances.—Take two bullets, and having flattened and cleaned one side of each, press them together with a twisting motion. They will cohere when the molecules are crowded into apparent contact.*—If two globules of mercury be brought near each other, at the instant they seem to touch they will suddenly coalesce.—Two freshly-cut surfaces of rubber, when warmed and pressed together, will cohere as if they formed one piece. —The process of welding illustrates this principle. A wrought-iron tool being broken, we wish to mend it. So we bring the iron to a white heat at the ends which we intend to unite. This partly overcomes the attraction of cohesion, and the molecules will move easily upon one another. Laying now the two heated ends upon each other, we pound them until the molecules are brought near enough for cohesion to grasp them.

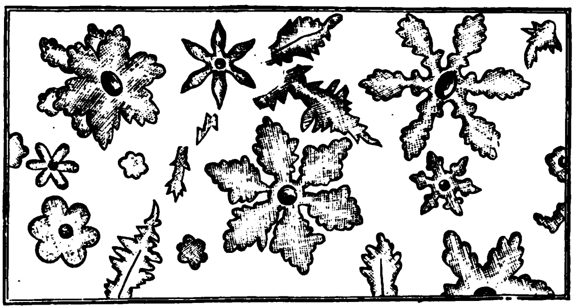
4. Liquids Tend to Form Spheres.—Mix a glass of water and alcohol in such proportion that a drop of sweet-oil will fall half-way to the bottom. It will there form a perfect sphere. The same tendency is seen in dew-drops, rain-drops, globules of quicksilver, and in the manufacture of shot. (*Chemistry*, p. 174.) The reason is that the force of cohesion acts toward the centre of the drop. In a spherical body, every portion of the surface is equally distant from the centre; and when that form is assumed, every molecule on the outside is equally attracted, and an equilibrium is established.

5. Solids Tend to Form Crystals.—When a liquid becomes a solid, the general tendency is to assume a sym-

* Surfaces may appear to the eye to be in contact when they are not actually so. Newton found, during some experiments on light (p. 168), that a convex lens or a watch-glass laid on a flat glass does not touch it, and cannot be made to do so, even by a force of many pounds.

metrical form. The attraction of cohesion strives to arrange the molecules in an orderly manner. Each kind of matter has its peculiar shape and angle, by which its crystals may be recognized.* When different substances are contained in the same solution, they separate on crystallization, and each molecule goes to its own. The exquisite beauty of these crystalline forms is seen in snowflakes and the frostwork traced on a cold morning upon the windows or the stone-flagging. A beam of light passed through a block of ice reveals these crystals as a mass of star-like flowers (Fig. 19).†

FIG. 19.



Melted iron rapidly cooled in a mould has not time to arrange its crystals. If, however, the iron be afterward violently jarred, as when used for cannon, rail-cars, etc., the

* Epsom salt crystallizes in four-sided prisms, common salt in cubes, and alum in octahedra. We can illustrate the formation of the last by adding alum to hot water until no more will dissolve. Then suspend strings across the dish and set it away to cool. Beautiful octahedral crystals will collect on the threads and sides of the vessel. The slower the process, the larger the crystals.—God delights in order as in beauty. Down in the dark recesses of the earth He has fashioned, by the slow processes of His laws, the rarest gems—amethysts, rubies, and diamonds. There are mountain masses transparent as glass, caves hung with stalactites, and crevices rich with gold and silver, and lined with quartz.

† It is noticeable that, as the crystals melt, at the centre of each liquid flower is a vacuum, showing that there is not enough water formed to fill the space occupied by the crystal, and that the solid contracts as it passes into a fluid (p. 202). This experiment is easily tried. The ice must be cut parallel to the plane of its freezing and be not over half an inch thick. A common oil-lamp will furnish the light.

molecules take on the crystalline form and the metal becomes brittle.*

6. Annealing and Tempering.—If a piece of wrought-iron be heated and then plunged into water, it becomes hard and brittle. If, on the contrary, it be heated and cooled slowly, it is made tough and flexible. Strangely enough, the same process which hardens iron softens copper. Steel is tempered by heating white-hot, then cooling quickly, and afterward re-heating and cooling slowly. The higher the temperature of the second heating, the softer the steel. (*Chemistry*, p. 152.)

7. The Rupert's Drop is a tear of melted glass dropped into water, and cooled quickly. As there is not time for the particles to assume their natural position, they exert a violent strain upon one another; and if the tail of the drop be nipped off, the tension will cause the mass to fly into powder with a sharp explosion. All glassware, when first made, is brittle, but it is annealed by being drawn slowly through a long oven, highly heated at one end, but quite cool at the other. During this passage, the molecules of glass have time to arrange themselves in a stable position.†

FIG. 20.

PRACTICAL QUESTIONS.—1. Why can we not weld a piece of copper to one of iron? 2. Why is a bar of iron stronger than one of wood? 3. Why is a piece of iron, when perfectly welded, stronger than before it was broken? 4. Why do drops of different liquids vary in size? 5. When you drop medicine, why will the last few drops contained in the bottle be of a larger size than the others? 6. Why are the drops larger if you drop them slowly? 7. Why is a tube stronger than a rod of the same weight? 8. Why, if you melt scraps of lead, will they form a solid mass when cooled? 9. In what liquids is the force of cohesion greatest? 10. Name some solids which volatilize without melting. 11. Why can glass be welded?

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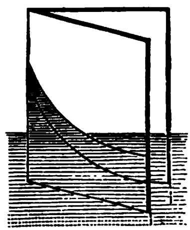
* On examining such a piece of iron, which can easily be procured at a car or machine-shop, we can see in a fresh fracture the smooth, shiny face of the crystals.

† "The restoration of cohesion is beautifully seen in the gilding of china. A figure is drawn upon the china with a mixture of oxide of gold and an essential oil. The article is then heated, whereby the essential oil and the oxygen of the gold are expelled, and a red-brown pattern remains. This consists of pure gold in a finely-divided state, without lustre. By rubbing with a hard burnisher, the particles of gold cohere and reflect the rich yellow color of the polished metal."

2. ADHESION.

1. Adhesion is the force which holds together molecules of different kinds. Ex.: Two pieces of wood are fastened together with glue, two pieces of china with cement, two bricks with mortar, two sheets of paper with mucilage, and two pieces of tin with solder. Syrup and coal-oil are purified by filtering through animal charcoal. Bubbles can be blown from soap-suds, because the soap by its adhesive force holds together the particles of water.

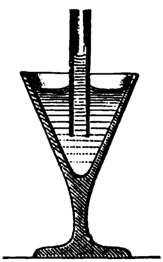
FIG. 21.



2. Capillary Attraction (*capillus*, hair) is a variety of adhesion between solids and liquids. It may be seen when two panes of glass are placed as shown in Fig. 21, but is exhibited most strikingly in very fine tubes, whence the name.*

If we insert a glass tube in *water*, the liquid will rise in it. The finer the bore of the tube, the higher the ascent. In this case, it is evident that the adhesion between the glass and the water is greater than the cohesion of the water. There is an *attraction* between the glass and the water.

FIG. 22.

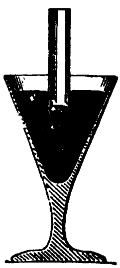


If we insert a glass tube in *mercury*, the capillary attraction will be reversed, and the height of the liquid be lower than the general level. In this case the adhesion between the glass and the mercury is less

* These tubes may be drawn by the pupil to any length and size, from French-glass tubing, in the heat of a common alcohol-lamp.—Capillarity is explained by recent physicists on the principle of "surface-tension." All parts of a liquid body except the surface, being drawn in every direction by cohesion, are mobile. The surface, however, is drawn only downward, and is in a state of tension like the film of a soap-bubble. See full explanation in Maxwell's *Theory of Heat*, p 280, and Everett's *Deschanel's Philosophy*, p. 130.

than the cohesion of the mercury. There is an apparent *repulsion* between the glass and the mercury.

FIG. 23.



ILLUSTRATIONS.—The wick of a lamp or candle is a bundle of capillary tubes, which elevate the oil or melted fat and feed the flame.—If the end of a towel be dipped in a basin of water, the whole towel will soon be wet by capillary action through the pores of the cloth.—Blotting-paper takes up ink by capillarity.—Water in the saucer of a flower-pot is elevated through the pores of the earth to the plant.*—Ropes absorb water by capillary action, swell, and shrink often to breaking.†

3. Solution.—Sugar will dissolve in water, because the adhesion between the two substances is stronger than the cohesion of the sugar.‡ As heat weakens cohesion, it

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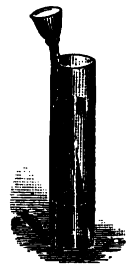
* In the same way, water is drawn to the surface of the ground to furnish vegetation with the materials of growth. Even in the winter, when the surface is frozen, the water still finds its way upward, and freezes into ice, which in the spring produces mud, although there may have been little rain or snow. Stirring the ground causes it better to endure drought, because the size of the capillary pores is increased, thus preventing the water from being carried to the surface and evaporated.

† It is 1586. The Egyptian obelisk, weighing a million pounds, is to be raised in the square of St. Peter's, Rome. Pope Sixtus V proclaims that no one shall utter a word aloud until the engineer announces that all danger is passed. As the majestic column ascends, all eyes watch it with wonder and awe. Slowly it rises, inch by inch, foot by foot, until the task is almost completed, when the strain becomes too great. The huge ropes yield and slip. The workmen are dismayed, and fly wildly to escape the impending mass of stone. Suddenly a voice breaks the silence. "*Wet the ropes*," rings out clear-toned as a trumpet. The crowd look. There, on a high post, standing on tiptoe, his eyes glittering with the intensity of excitement, is one of the eight hundred workmen, a sailor named Bresca di S. Remo. His voice and appearance startle every one; but his words inspire. He is obeyed. The ropes swell and bite into the stone. The column ascends again, and in a moment more stands securely on its pedestal. The daring sailor is not only forgiven, but his descendants to this day enjoy the reward of providing the palm-branches used on Palm Sunday at St. Peter's.

‡ This contest between adhesion and cohesion is seen when we let fall on water a drop of oil. Adhesion tends to draw the oil to the liquid, so as to mix thoroughly, and cohesion to prevent this. The extent to which the drop will spread will depend on the relation of the two attractions, and vary for every substance. Thus each oil has its own COHESION FIGURE, which enables the chemist readily to detect differences and mixtures. Experiments: Dissolve a little salt in a glass of water, and touch

hastens solution, so that a substance generally dissolves more rapidly in hot water than in cold. In like manner, pulverizing a solid aids solution. Liquids also absorb gases by adhesion. Thus water contains air, which renders it pleasant to the taste. As pressure and cold weaken the repellent force, they favor the adhesion between the molecules of a gas and water. Soda-water receives its effervescence and pungent taste from carbonic-acid gas, which, being absorbed under great pressure, escapes in sparkling bubbles when the pressure is removed.

FIG. 24.



4. Diffusion of Liquids.—Let a jar be partly filled with water colored by blue litmus. Then, by a funnel-tube, pour clear water containing oil of vitriol to the bottom, beneath the colored water. At first, the two will be distinctly defined, but in a few days they will mix, as will be seen by the change of color from blue to red. A drop of oil of vitriol may thus be distributed through a quart of water. Most liquids will mingle when brought in contact.* If, however, there is no adhesion between their molecules, they will not mix, and will separate even after having been thoroughly shaken together.

FIG. 25.

5. Diffusion of Gases.—Hydrogen gas is only $\frac{1}{14}$ as heavy as common air. Yet, if two bottles be arranged as in Fig. 25, the lower one filled with the heavy gas, and the upper with the lighter, the gases will soon be uniformly mixed.†

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the surface of the liquid with a pen full of ink. The characteristic figures wil quickly appear.—Dissolve in water a pinch of salt and a lump of loaf-sugar. Touch the surface with lunar caustic. The figure of nitrate of silver will be seen.

* A story is told of some negroes in the West Indies who supplied themselves with liquor by inverting the neck of a bottle of water in the bung-hole of a cask of rum. The water sank into the barrel, while the rum rose to take its place.

† This phenomenon is explained by the theory that the molecules of all bodies are in rapid motion. As the worlds in space are clustered in mighty systems, the mem-

6. Osmose of Liquids.—When two liquids are separated by a thin porous substance, the interchange is modified in a curious manner, according to the nature of the liquid and the substance used. At the end of a glass tube (Fig. 26) fasten a bladder of alcohol. Fill the jar with water, and mark the height to which the alcohol ascends in the tube.

FIG. 26.

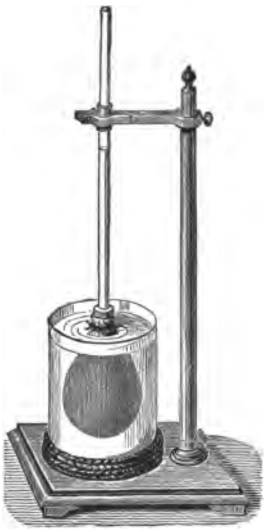

FIG. 27.

The column will soon begin to rise slowly. On examination, we shall see that the alcohol is passing out through the pores of the bladder and mixing with the water, while the water

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bers of each revolving about one another in inconceivably *vast* orbits, so each body is a miniature system, its molecules moving in inconceivably *minute* paths. In a gas, the molecular velocity is enormous. The particles of ammonia gas, for example, are flying to and fro at the rate of twenty miles per minute. "Could we, by any means," says Prof. Cooke, "turn in one direction the actual motion of the molecules of what we call still air, it would become at once a wind blowing seventeen miles per minute, and exert a destructive power compared with which the most violent tornado is feeble."—Invert a bottle over a lighted candle, and the oxygen of the enclosed air being soon consumed, the flame goes out. Instead of the bottle, use a foolscap-paper cone. There will be an interchange of gases through the pores of the paper and the light will burn freely.

is coming in more rapidly. In most other cases of endosmose, the flow is toward the denser liquid.

The chemist uses a method of separating substances in solution, termed ***dialysis***, that is based on their unequal diffusibility.

7. Osmose of Gases.—Fit a porous cup used in Grove's Battery (p. 234) with a cork and glass tube, as in Fig. 27. Fasten the tube so that it will dip beneath the water in the glass. Then invert over the cup a jar of hydrogen. The gas will pass through the pores of the earthenware and down the tube so rapidly, as almost instantly to bubble up through the water.*

PRACTICAL QUESTIONS.—1. Why does cloth shrink when wet? 2. Why do sailors at a boat-race wet the sails? 3. Why is writing-paper sized? 4. Why does paint prevent wood from shrinking? 5. What is the shape of the surface of a glass-full of water? Of mercury? 6. Why can we not perfectly dry a towel by wringing? 7. Why will not water run through a fine sieve when the wires are greased? 8. Why will camphor dissolve in alcohol, and not in water? 9. Why will mercury rise in zinc tubes as water will in glass tubes? 10. Why is it so difficult to lift a board out of water? 11. Why will ink spilled on the edge of a book extend farther inside than if spilled on the side of the leaves? 12. If you should happen to spill some ink on the edge of your book, ought you to press the leaves together? 13. Why can you not mix water and oil? 14. What is the object of the spout on a pitcher? *Ans.* The water would run down the side of the pitcher by the force of adhesion, but the spout throws it into the hands of gravitation before adhesion can catch it. 15. Why will water wet your hand, while mercury will not? 16. Why is a pail or tub liable to fall to pieces if not filled with water or kept in a damp place? 17. Name instances where the attraction of adhesion is stronger than that of cohesion. 18. Why does the water in Fig. 22 stand higher inside of the tube than next the glass on the outside? 19. Why will clothes-lines tighten and sometimes break during a shower? 20. Show that the law of the diffusion of gases aids in preserving the purity of the atmosphere. 21. In casting large cannon, the gun is cooled by a stream of cold water. Why? 22. Why does paint adhere to wood? Chalk to the blackboard? 23. Why does a towel dry one's face after washing? 24. Why will a greased needle float on water? 25. Why is the point of a pen slit? 26. Why is a thin layer of glue stronger than a thick one?

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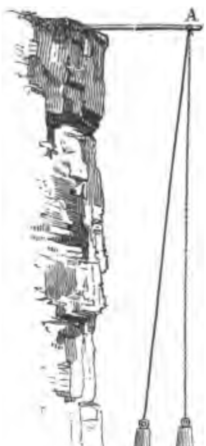
* Rose balloons lose their buoyancy, because the hydrogen escapes through the pores of the rubber. If they were filled with air and placed in a jar of hydrogen, that gas would creep in so rapidly as to burst them.—The quicker flow from the thinner to the thicker fluid is termed *endosmose*, and the opposite, slower current, *exosmose*. —In performing the experiment shown in Fig. 27, coal-gas may be used.

II. ATTRACTION OF GRAVITATION.

We have spoken of the attraction existing between the molecules of bodies at minute distances. We now notice an attraction which acts at all distances.

1. Law of Gravitation.—Hold a stone in the hand, and you feel a power constantly drawing it to the ground. We call this familiar phenomenon *weight*. It is really the attraction of the earth pulling the stone back to itself—an instance of a general law, one operation of an ever-active force. For *every particle of matter in the universe* attracts every other particle, the force exerted between any two particles being directly proportional to the product of their masses, and inversely as the square of their distance apart.*

Fig. 28.



Gravitation is the general term for the attraction that exists between all bodies in the universe. *Gravity* is the earth's attraction for terrestrial bodies; it tends to draw them toward the centre of the earth. *Weight* is the measure of the force of gravity. When we say that a body weighs 10 lbs., we mean that the earth attracts it that amount.

2. Illustrations of Gravity.—A stone falls to the ground because the

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* The force of gravitation resides in every particle of matter, and hence it is not confined to our own world. By its action the heavenly bodies are bound to one another, and thus kept in their orbits. It may help us to conceive how the earth is supported, if we imagine the sun letting down a huge cable, and every star in the heavens a tiny thread, to hold our globe in its place, while it in turn sends back a cable to the sun and a thread to every one of the stars. So we are bound to them and they to us. Thus the worlds throughout space are linked together by these cords of mutual attraction, which, interweaving in every direction, make the universe a unit.

earth attracts it; but in turn the stone attracts the earth. Each moves to meet the other, but the stone passes through as much greater distance than the earth as its mass is less. The mass of the earth is so great that its motion is imperceptible.—A plumb-line hanging near a mountain is attracted from the vertical. In Fig. 28, AB represents the ordinary position of the line, while AC indicates the attractive power (exaggerated) of the mountain.*

3. Laws of Weight.—I. *The weight of a body at the centre of the earth is nothing,* because the attraction there is equal in every direction.

II. *The weight of a body above the surface of the earth decreases as the square of the distance from the centre of the earth increases.*†

III. *The weight of a body varies on different portions of the surface of the earth.*‡ It will be least at the equator, because (1), on account of the bulging form of our globe, a body is pushed out from the mass of the earth, and so removed from the centre of attraction; and (2), the centrifugal force is the strongest. It will be the greatest at the poles, because (1), on account of the flattening of the earth, a body is

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* Maskelyne, in 1774, found the attraction of Mount Schihallion to be 12″. By comparing this force with that of the earth, the specific gravity of the mountain being known, the specific gravity of the earth was estimated to be 5 times that of water. Later investigations make it 5.67.

† A body at the surface of the earth (4000 miles from the centre) weighs 100 lbs. What would be its weight 1000 miles above the surface (5000 miles from the centre)? SOLUTION. $(5000 \text{ mi.})^2 : (4000 \text{ mi.})^2 :: 100 \text{ lbs.} : x = 64 \text{ lbs.}$ Or, its weight would decrease in the ratio of $\frac{4000^2}{5000^2} = \frac{16}{25}$. Hence it would weigh $\frac{16}{25} \times 100 \text{ lbs.} = 64 \text{ lbs.}$—The weight of a body below the surface of the earth is commonly said to decrease directly as the distance from the centre decreases. Thus, 1000 miles below the surface, a body would lose $\frac{1}{4}$ its weight. In fact, however, the density of the earth increases so much toward the centre, that for "$\frac{7}{10}$ of the distance the force of gravity actually becomes stronger than on the surface."

‡ In these statements concerning weight, a spring-balance is supposed to be employed. With a pair of scales, the weights used would become heavier or lighter in the same proportion as the body to be weighed. If a spring-scale be graduated to indicate correctly at a medium latitude, it would show too little at the equator, and too much at the poles. In other words, a pound weighed by such a spring-scale at the equator would contain a greater mass of matter than one weighed at the poles by about $\frac{1}{194}$ part.

brought nearer its mass and the centre of attraction; and (2), there is no centrifugal force at those points.

4. Falling Bodies.—Since the attraction of the earth is toward its centre, bodies falling freely move in a direct line toward that point. This line is called a *vertical* or *plumb-line.**

Fig. 29.

(1.) Laws of Falling Bodies.—I. *Under the influence of gravity alone, all bodies fall with equal rapidity.* This is well illustrated by the "guinea-and-feather experiment." Let a coin and a feather be placed in a tube, and the air exhausted. Quickly invert the tube, and the two bodies will fall in the same time. Let in the air again, and the feather will flutter down long after the coin has reached the bottom.† Hence we conclude that in a vacuum all bodies descend with equal velocity, and that the resistance of the air is the cause of the variation we see between the falling of light and of heavy bodies.

II. *In the first second a body gains a velocity of* 32 *feet and falls* 16 *feet.*‡—This has been proved by careful experiments. Notice that 16 feet, the distance passed through the first second, is the mean between 0, the velocity at the beginning, and 32, the velocity at the close.

* From *plumbum*, lead, because a lead weight is used by mechanics in finding it. All plumb-lines point very nearly toward the centre of the earth.

† The same fact may be noticed in the case of a sheet of paper. When spread out, it merely flutters to the ground; but when rolled in a compact mass, it falls like lead. In this case we have not increased the force of attraction, but we have diminished the resistance of the air.

‡ More exactly, at the latitude of New York a body will fall in a vacuum 16.08 feet the first second, and gain a velocity of 32.16 feet. 16 ft.=4.9 m. 32 ft.=9.8 m.=980 cm.

III. *At the end of any given second, the velocity is* 16 *feet multiplied by twice the number of the second; and the distance passed through during that second is* 16 *feet multiplied by twice the number of the second minus one.* In other words, the velocities are as the corresponding even numbers, 2, 4, 6, 8, etc., and the distances as the odd * numbers, 1, 3, 5, 7, etc.

The body commences the second second with a velocity of 32 feet, and as gravity is a constant force, gains 32 feet during the second, making 64 feet $= 4 \times 16$ feet. It commences the third second with a velocity of 64 feet, and gains 32 feet, making 96 feet $= 6 \times 16$ feet. The mean between 32 feet, the velocity at the beginning of the second second, and 64 feet, the velocity at the close, is 48 feet $= 3 \times 16$ ft. The mean between 64 feet, the velocity at the beginning of the third second, and 96 feet, the velocity at the close, is 80 feet $= 5 \times 16$ feet.

IV. *In any number of seconds a body falls* 16 *feet multiplied by the square of the number of seconds.*

We have just seen that a body falls 16 feet the first second and 48 feet the second. Hence in two seconds it falls 16 feet + 48 feet = 64 feet $= 2^2 \times 16$ feet. In three seconds it falls 16 + 48 + 80 feet = 144 feet $= 3^2 \times 16$ feet.

(2.) Equations of Falling Bodies.—If we represent the velocity of a falling body by v, the distance in any second by s, the total distance by d, and the time by t, the following equations can be derived from the foregoing laws:

$v = 32t$..(1). $d = 16t^2$..(2). $v^2 = 64d$..(3). $s = 16(2t - 1)$..(4).

If g represent the constant force of gravity, a velocity of 32 feet per second, we have,

$v = gt$....(5). $t = \sqrt{\dfrac{2d}{g}}$....(7). $t = \dfrac{v}{g}$........... (9).

$d = \frac{1}{2}gt^2$..(6). $v = \sqrt{2gd}$....(8). $s = \frac{1}{2}g(2t - 1)$....(10).

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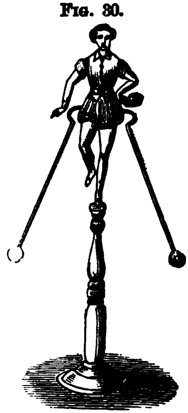
* It will aid the memory, if we associate *d* in "distance" and "odd," and *v* in "velocity" and "even."—To find the odd number corresponding to any second, double the number of the second and subtract one. See Explanatory Tables, p. 273.

(3.) To Find the Depth of a Well.—Let a stone fall into it, and, with a watch or by the beat of the pulse, count the seconds that elapse before you hear it strike the bottom. Square the number of seconds, multiply 16 feet by the result, and the product is the depth.*

(4.) When a Body is Thrown Upward, the same principles apply, it losing through gravity 32 feet in velocity each second. The velocity necessary to elevate it to a certain point must be what it would acquire in falling that distance.† It will rise just as high in a given time as it would fall in the same time. If a ball be thrown vertically into the air, it will be as long in falling as in rising. In theory, it will strike the earth with the same force with which it was thrown; in practice, however, it loses about $\frac{1}{6}$ of its force in rising and an equal amount in falling, owing to the resistance of the air.

5. The Centre of Gravity is that point on which, if supported, a body will balance itself. The *line of direction* is a vertical drawn from the centre of gravity; it is the line along which the centre of gravity would pass, if the body should fall. When a body is at rest, the forces which act on every molecule in it are said to balance one another, or to be in *equilibrium*.

Fig. 30.



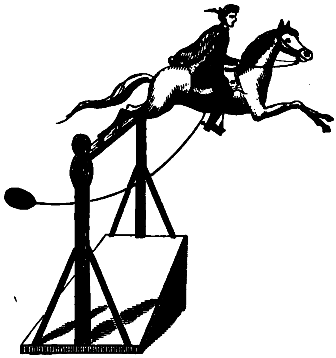
(1.) Three States of Equilibrium.—1st. A body is in *stable equilibrium* when the centre of gravity is below the point of support, or when any movement tends to raise the centre of gravity. In Fig. 30, the image has the centre of gravity lowered below the point of support by means of

* A little time is required for the sound to come to the ear, but this is so slight that it may be neglected.

† If a body be thrown upward with a velocity of 128 feet, by applying equation (9), $t = \frac{v}{g}$, we find that it will rise for 4 seconds.

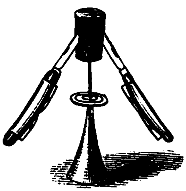
lead balls. Remove these, and it immediately falls, but with them it is in stable equilibrium. Any movement of the toy shown in Fig. 31 tends to raise the centre of gravity, and it returns quickly to a state of rest.—A needle may be balanced on its point by a cork and two jack-knives (Fig. 32), which lower its centre of gravity.

Fig. 31.



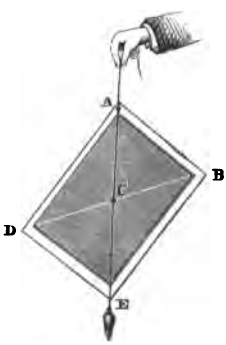
2d. A body is said to be in *unstable equilibrium* when the centre of gravity is above the point of support, or when any movement tends to lower the centre of gravity. If we take the cork as arranged with the knives in Fig. 32, and invert it, we shall have difficulty in balancing the needle; and, if we succeed, it will readily topple off, as the least motion tends to lower the centre of gravity.

Fig. 32.



3d. A body is said to be in *indifferent equilibrium* when the centre of gravity is at the point of support, or when any movement tends neither to elevate nor lower the centre of gravity. A ball of uniform density on a level surface will rest in any position, because the centre of gravity moves in a line parallel to the floor.

Fig. 33.



(2.) The Centre of Gravity may be Found either by balancing the body, or by suspending it from two corners, successively, as in Fig. 33. By a plumb-line obtain the

line of direction AE; then hang the slate from another corner, and mark the line of direction BD. The point C, where the two lines cross, is the centre of gravity.

(3.) General Principles.—(*a.*) The centre of gravity tends to seek the lowest point.

(*b.*) A body will not tip over while the line of direction falls within the base, but will as soon as it falls without.*

(*c.*) In general, narrowness of base combined with height of centre of gravity, tends to instability; † breadth of base and lowness of centre of gravity, produce stability.

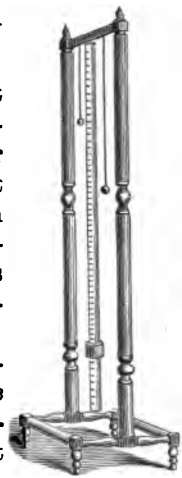
(4.) Physiological Facts.—Our feet and the space between them form the base on which we stand. By turning our toes outward, we increase its breadth. When we stand on one foot, we bend over so as to bring the line of direction within this narrower base. When we walk, we incline to the right and the left alternately. When we carry a pail of water, we balance it by leaning in the opposite direction. When we walk up hill we lean forward, and in going down hill we incline backward, in unconscious obedience to the laws of gravity. We bend forward when we wish to rise from a chair, in order to bring the centre of gravity over our feet, our muscles not having sufficient strength to raise our bodies without this aid. When we walk, we lean forward, so as to bring the centre of gravity as far in front as possi-

* The Leaning Tower of Pisa, in Italy, beautifully illustrates this principle (see Frontispiece). It is about 188 feet high, and its top leans 15 feet, yet the line of direction falls so far within the base that it is perfectly stable, having stood for seven centuries. The feeling experienced by a person who for the first time looks down from the lower side of the top of this apparently impending structure is startling indeed.

† This is shown by the difficulty in learning to walk upon stilts. The art of balancing one's self may, however, be acquired by practice, as is seen in the Landes of southwestern France. During a portion of the year these sandy plains are half-covered with water, and in the remainder are still very bad walking. The natives accordingly double the length of their legs by stilts. Mounted on these wooden poles, which are put on and off as regularly as the other parts of their dress, they appear to strangers as a new and extraordinary race, marching with steps of six feet in length, and with the speed of a trotting-horse. While watching their flocks, they support themselves by a third staff behind, and then w'th their rough sheep-skin cloaks and caps, like thatched roofs, seem to be little watch-towers, or singular lofty tripods, scattered over the country.—(*Arnott.*)

ble. Thus, walking is a process of falling. When we run, we lean further forward, and so fall faster. (*Phys.*, p. 49.)

Fig. 34.



6. The Pendulum consists of a weight so suspended as to swing freely. Its movements to and fro are termed *vibrations* or *oscillations.* The path through which it passes is called the *arc.* The extent to which it goes in either direction is styled its *amplitude.* Vibrations performed in equal times are termed *i-soch'-ro-nous* (*isos,* equal ; *chronos,* time).

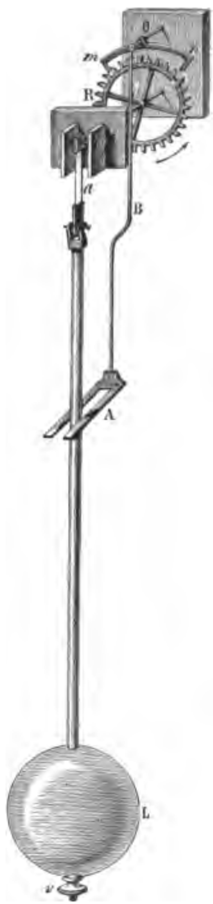
(1.) Three Laws.—I. *In the same pendulum, all vibrations of small amplitude are isochronous.* If we let one of the balls represented in Fig. 34 swing through a short arc, and then through a longer one, on counting the number of oscillations per minute, we shall find them very uniform.

Fig. 35.

II. *The times of the vibrations of different pendulums are proportional to the square roots of their respective lengths.* Ex.: A pendulum $\frac{1}{9}$ the length of another, will vibrate three times as fast.* Conversely, the lengths of different pendulums are proportional to the squares of their times of vibration.

* A pendulum which vibrates seconds must be four times as long as one which vibrates half-seconds. The apparatus represented in Figs. 34 and 35 can be made by any carpenter or ingenious pupil, and will serve excellently to illustrate the three laws of the pendulum.

FIG. 36.



III. *The time of the vibration of the same pendulum will vary at different places,* since it decreases as the square root of the force of gravity increases. At the equator a pendulum vibrates most slowly, and at the poles most rapidly. The length of a seconds-pendulum at New York is about $39\frac{1}{10}$ inches.

(2.) CENTRE OF OSCILLATION.—The upper part of a pendulum tends to move faster than the lower part, and so hastens the speed. The lower part of a pendulum tends to move slower than the upper part, and so retards the speed. Between these extremes is a point which is neither quickened nor impeded by the rest, but moves in the same time that it would if it were a particle swinging by an imaginary line. This point is called the *centre of oscillation.* It lies a little below the centre of gravity.* In Fig. 35 is shown an apparatus containing pendulums of different shapes, but of the same length. If they are started together, they will immediately diverge, no two vibrating in the same time. As pendulums, they are not of the same length.

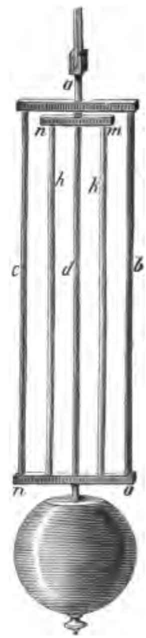
(3.) THE CENTRE OF OSCILLATION IS FOUND BY TRIAL.—Huygens discovered that the point of suspension and the centre of oscillation are interchangeable. If, therefore, a pendulum be inverted, and a point found at which it will vibrate in the same time as before,

* This determines the real length of a pendulum, which is the distance from the point of support to the centre of oscillation. The imaginary pendulum above described is known in Physics as the *Simple Pendulum.*—39.1 inches = 993.3 mm.

this is the former centre of oscillation; while the old point of suspension becomes the new centre of oscillation.*

(4.) THE PENDULUM AS A TIME-KEEPER.—The friction at the point of suspension, and the resistance of the air, soon destroy the motion of the pendulum. The clock is a machine for keeping up the vibration of the pendulum, and counting its beats. In Fig. 36, R is the scape-wheel driven by the force of the clock-weight or spring, and *mn* the escapement, moved by the forked arm AB, so that only one cog of the wheel can pass at each double vibration of the pendulum. Thus the oscillations are counted by the cogs on the wheel, while the friction and the resistance of the air are overcome by the action of the weight or spring.† As "heat expands and cold contracts," a pendulum lengthens in summer and shortens in winter. A clock, therefore, tends to lose time in summer and gain in winter. To regulate a clock, we raise or lower the pendulum-bob, L, by the nut *v*.

FIG. 37.



The *gridiron pendulum* consists of brass and steel rods, so connected that the brass, *h*, *k*, will lengthen upward, and the steel *a*, *b*, *c*, *d*, downward, and thus the centre of oscillation remain unchanged. The *mercurial pendulum* contains a cup of mercury which expands upward while the pendulum-rod expands downward.

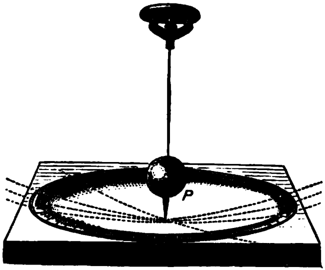
(5.) OTHER USES OF THE PENDULUM.—(*a.*) Since the time of vibration of a pendu-

* The centre of oscillation is the same as the *centre of percussion*. The latter is the point where we must strike a suspended body, if we wish it to revolve about its axis without any strain. If we do not hit a ball on the bat's centre of percussion, our hands "sting" with the jar. (See note, p. 260.)

† The action of a clock is clearly seen by procuring the works of an old clock and watching the movements of the various parts.

lum indicates the force of gravity, and the force of gravity decreases as the square of the distance from the centre of the earth increases, we may thus find the semi-diameter of the earth at various places, and ascertain the figure of our globe. (*b.*) Knowing the force of gravity at any point, the velocity of a falling body can be determined. (*c.*) The pendulum may be used as a standard of measures. (*d.*) Foucault devised a method of showing the revolution of the earth on its axis, founded upon the fact that the pendulum vibrates constantly in one plane.* (*e.*) By observing the difference in the length of a seconds-pendulum at the top of a mountain and at the level of the sea, the density of the earth may be estimated.

FIG. 38.



PRACTICAL QUESTIONS.—1. When an apple falls to the ground, how much does the earth rise to meet it? 2. What causes the sawdust on a mill-pond to collect in large masses? 3. Will a body weigh more in a valley than on a mountain? 4. Will a pound weight fall more slowly than a two-pound weight? 5. How deep is a well if it takes three seconds for a stone to fall to the bottom? 6. Is the centre of gravity always within a body—as, for example, a pair of tongs? 7. If two bodies, weighing respectively 2 and 4 lbs., be connected by a rod 2 feet long, where is the centre of gravity? 8. In a ball of equal density throughout, where is the centre of gravity? 9. Why does a ball roll down hill? 10. Why is it easier to roll a round body than a square one? 11. Why is it easier to tip over a load of hay than one of stone? 12. Why is a pyramid such a stable structure? 13. When a hammer is thrown, on which end does it strike? 14. Why does a rope-walker carry a heavy balancing-pole? 15. What would become of a ball if dropped into a hole bored through the centre of the earth? 16. Would a clock lose or gain time if carried to the top of a mountain? If carried to the North Pole? 17. In the winter, would you raise or lower the pendulum-bob of your clock? 18. Why is the pendulum-bob always made flat? 19. What

* A pendulum 220 feet in length was suspended from the dome of the Pantheon in Paris. The lower end of the pendulum traced its vibrations north and south upon a table beneath, sprinkled with fine sand. These paths did not coincide, but at each return to the outside, the pendulum marked a point to the left. At the poles of the earth, the pendulum, constantly vibrating in the same vertical plane, would perform a complete revolution in 24 hours, making thus a kind of clock. At the equator it would not change east or west, as the plane of vibration would go forward with the diurnal revolution of the earth. The shifting of the plane would increase as the pendulum was carried north or south from the equator.

"beats off" the time in a watch? 20. What should be the length of a pendulum to vibrate minutes at the latitude of New York? *Solution.* (1 sec.)^2 : (60 sec.)^2 :: 39.1 in. : x=2.2+ miles. 21. What should be the length of the above to vibrate half-seconds? Quarter-seconds? Hours? 22. What is the proportionate time of vibration of two pendulums, respectively 16 and 64 inches long? 23. Why, when you are standing erect against a wall, and a piece of money is placed between your feet, can you not stoop forward and pick it up? 24. If a tower were 198 feet high, with what velocity would a stone, dropped from the summit, strike the ground? 25. A body falls in 5 seconds; with what velocity does it strike the ground? 26. How far will a body fall in 10 seconds? With what velocity will it strike the ground? 27. A body is thrown upward with a velocity of 192 feet the first second; to what height will it rise? 28. A ball is shot upward with a velocity of 256 feet; to what height will it rise? How long will it continue to ascend? 29. Why do not drops of water, falling from the clouds, strike with a force proportional to the laws of falling bodies? *Ans.* Because they are so small that the resistance of the air nearly destroys their velocity. If it were not for this wise provision, a shower of rain-drops would be as fatal as one of Minie bullets. 30. Are any two plumb-lines parallel? 31. A stone let fall from a bridge strikes the water in 3 seconds. What is the height? 32. A stone falls from a church-steeple in 4 seconds. What is the height of the steeple? 33. How far would a body fall in the first second at a distance of 12,000 miles above the earth's surface? 34. A body at the surface of the earth weighs 100 tons what would be its weight 1,000 miles above? 35. A boy wishing to find the height of a steeple, lets fly an arrow that just reaches the top and then falls to the ground. It is in the air 6 seconds. Required the height. 36. A cat let fall from a balloon reaches the ground in 10 seconds. Required the distance. 37. In what time will a pendulum 40 feet long make a vibration? 38. Two meteoric bodies in space are 12 miles apart. They weigh respectively 100 and 200 lbs. If they should fall together by their mutual attraction, what portion of the distance would be passed over by each body? 39. If a body weighs 2,000 lbs. upon the surface of the earth, what would it weigh 2,000 miles above? 500 miles above? 40. At what distance above the earth will a body fall, the first second, 21¼ inches? 41. How far will a body fall in 8 seconds? In the 8th second? In 10 seconds? In the 30th second? 42. How long would it take for a pendulum one mile in length to make a vibration? 43. How long would it take for a pendulum reaching from the earth to the moon to make a vibration? 44. Required the length of a pendulum that would vibrate centuries. 45. What would be the time of vibration of a pendulum 64 metres long? 46. A ball is dropped from a height of 64 feet. At the same moment a second ball is thrown upward with sufficient velocity to reach the same point. Where will the two balls pass each other? 47. Two bodies are successively dropped from the same point with an interval of ½ of a second. When will the distance between them be one metre? 48. Explain the following fact: A straight stick loaded with lead at one end, can be more easily balanced vertically on the finger when the loaded end is upward than when it is downward. 49. What effect would the fall of a heavy body to the earth have upon the motion of the earth in its orbit? (In answering this question, imagine the body to fall in various directions toward the earth, as opposed to the motion of the earth, in the same direction with the earth's motion, etc.) 50. If a body weighing a pound on the earth were carried to the sun it would weigh about 27 pounds. How much would it then attract the sun? 51. Why does watery vapor float and rain fall? 52. If a body weighs 10 kilos. on the surface of the earth, what would it weigh 1,000 kilometres above (the earth's radius being 6.366 km.)? 53. A body is thrown vertically upward with a velocity of 100 metres; how long before it will return to its original position? 54. Required the time needed for a body to fall a distance of 2,000 metres. 55. If two bodies, weighing respectively 1 kilo. and 1 demi-kilo., are connected by a rod 90 centimetres long, where is the centre of gravity?

SUMMARY.

There are certain forces residing in molecules and acting only at insensible distances, which are known as the Molecular Forces. The one which ties together molecules of the same kind is styled cohesion. The relation between this force and that of heat determines whether a body is solid, liquid, or gaseous. Under the action of cohesion, liquids tend to form spheres; and solids, crystals. The processes of welding and tempering, and the annealing of iron and glass, illustrate curious modifications of the cohesive force. Molecules of different kinds are held together by adhesion. Its action is seen in the use of cement, paste, etc., in the solution of solids, in capillarity, diffusion of gases, and osmose.

Gravitation, though weak,* compared with cohesion, acts universally. Its force is directly as the product of the attracting and attracted masses, and inversely as the square of their distance apart. Gravity makes a stone fall to the ground. The earth and a kilogram of iron in mid-air attract each other equally, but the former is so much heavier that they move toward each other with unequal velocity, and the motion of the earth is imperceptible. Weight is the resisted attraction of the earth. At the centre of the earth the weight of a body would be nothing; at the poles it would be greatest, and at the equator least. Increase of distance above or far below the surface of the earth will diminish weight. Were the resistance of the air removed, all bodies would fall with equal rapidity. The first second a body falls 16 feet (4.9 metres), and gains a velocity of 32 feet (9.8 metres). In general, the velocity of a falling body is 16 feet, multiplied by the even number corresponding to the second, and the distance 16 feet multiplied by the odd number. The centre of gravity is the point about which the weights of all the particles composing a body will balance one another, *i. e.,* be in equilibrium. There are three states of equilibrium—stable, unstable, and indifferent—according as the point of support in a body is above, below, or at the centre of gravity. As the centre of gravity tends to seek the lowest point, its position determines the stability of a body. The centre of gravity may be found by trial or with a plumb-line. A body suspended so as to swing freely is a pendulum. The time of a pendulum's vibration is independent of its material, proportional to the square root of its length and

* As the attraction of gravitation acts so commonly upon great masses of matter, we are apt to consider it a tremendous force. We, however, readily detect its relative feebleness when we compare the weight of bodies with their tenacity. Ex.: Think how much easier it is to lift an iron wire against gravity than to pull it to pieces against cohesion.

variable according to the latitude. The pendulum is our time-keeper and useful in many scientific investigations.

We are so accustomed to see all the objects around us possess weight, that we can hardly conceive of a body deprived of a property which we are apt to consider as an essential attribute of matter. Nothing is more natural, apparently, than the falling of a stone to the ground. "Yet," says D'Alembert, "it is not without reason that philosophers are astonished to see a stone fall, and those who laugh at their astonishment would soon share it themselves, if they would reflect on the subject." Gravity is constantly at work about us, at one moment producing equilibrium or rest, and at another, motion. When it seems to be destroyed, it is only counterbalanced for a time, and remains, apparently, as indestructible as matter itself. The stability and the incessant changes of nature are alike due to its action. Not only do rivers flow, snows fall, tides rise, and mountains stand in obedience to gravitation, but smoke ascends and clouds float through the combined influence of heat and weight.

HISTORICAL SKETCH.

The latter part of the sixteenth century witnessed the establishment of the principles of falling bodies. Galileo, while sitting in the cathedral at Pisa (see Frontispiece) and watching the swinging of an immense chandelier which hung from its lofty ceiling, noticed that its vibrations were isochronous. This was the germ-thought of the pendulum and the clock. Up to his time it had been taught that a 4-lb. weight would fall twice as fast as a 2-lb. one. He proved the fallacy of this view by dropping from the Leaning Tower of Pisa balls of different metals—gold, copper, and lead. They all reached the ground at nearly the same moment. The slight variation he correctly accounted for by the resistance of the air, which was not the same for all.

Newton, as the story runs, was sitting in his garden one day, and noticed the fall of an apple. Reflecting upon the force which drew it to the ground, the thought struck his mind that perhaps the same force acted upon the heavenly bodies. The moon, for example, revolves about the earth in a fixed orbit. Might it not be the attraction of the earth which causes the moon to move in this curved path? To test this, he calculated how far the moon bends from a straight line, *i. e.*, falls toward the earth every second. Knowing the distance a body falls in a second at the surface of the earth, he endeavored to see how far it would fall at the distance of the moon. For years he toiled over

this problem, but an erroneous estimate of the earth's diameter then accepted by physicists prevented his obtaining a correct result. Finally, a more accurate measurement having been made, he inserted this in his calculations. Finding the result was likely to verify his conjecture, his hand faltered with the excitement, and he was forced to ask a friend to complete the task. The truth was reached at last, and the grand law of gravitation discovered (1682).

The sun-dial was doubtless the earliest device for keeping time. The clepsydra was afterward employed. This consisted of a vessel containing water, which slowly escaped into a dish below, in which was a float that by its height indicated the lapse of time. King Alfred used candles of a uniform size, six of which lasted a day. The first clock erected in England, about 1288, was considered of so much importance that a high official was appointed to take charge of it. The clocks of the middle ages were extremely elaborate. They indicated the motions of the heavenly bodies; birds came out and sang songs, cocks crowed, and trumpeters blew their horns; chimes of bells were sounded, and processions of dignitaries and military officers, in fantastic dress, marched in front of the dial and gravely announced the time of day. Watches were made at Nuremberg in the fifteenth century. They were styled Nuremberg eggs. Many were as small as the watches of the present day, while others were as large as a dessert-plate. They had no minute or second hand, and required winding twice per day.

On Attraction, as well as on subsequent topics treated in this book, consult Guillemin's "Forces of Nature"; Atkinson's Ganot's Physics; Arnott's "Elements of Physics"; Snell's Olmstead's Natural Philosophy; Todhunter's "Philosophy for Beginners"; Stewart's Elementary Physics; Silliman's Physics; Everett's "Text-book of Physics"; Young's "Lectures on Natural Philosophy"; Thomson and Tait's "Elements of Natural Philosophy"; "Appleton's Cyclopædia," Articles on Clocks and Watches, Weights and Measures, Gravitation, Mechanics, etc.; Peck's Ganot's Natural Philosophy; Miller's Chemical Physics, Chap. III, on Molecular Force; Weinhold's Experimental Physics; Pickering's "Elementary Physical Manipulation"; Fourteen Weeks in Astronomy, Sections on Galileo and Newton, pp. 29-34.

The current numbers of Harper's Magazine (Editor's Scientific Record); Scribner's Magazine (The World's Work); Popular Science Monthly; Boston Journal of Chemistry, and the Scientific American contain the latest phases of science.

IV.

ELEMENTS OF MACHINES.

Nature is a reservoir of power. Tremendous forces are all about us, but they are not adapted to our use. We need to remould the energy to fit our wants. A waterfall cannot grind corn nor the wind draw water. Yet a machine will gather up these wasted forces, and turn a grist-mill or work a pump. A kettle of boiling water has little of promise; but husband its energy in the steam-engine, and it will weave cloth, forge an anchor, or bear our burdens along the iron track.

"*The hero in the fairy tale had a servant who could eat granite rocks, another who could hear the grass grow, and a third who could run a hundred leagues in half an hour. So man in nature is surrounded by a gang of friendly giants who can accept harder stints than these. There is no porter like gravitation, who will bring down any weight you cannot carry, and if he wants aid, knows how to get it from his fellow-laborers. Water sets his irresistible shoulder to your mill, or to your ship, or transports vast boulders of rock, neatly packed in his iceberg, a thousand miles.*"

—EMERSON

ANALYSIS.

ELEMENTS OF MACHINES.

- —THE SIMPLE MACHINES.
- —THE LAW OF MECHANICS.
- 1. THE LEVER.
  - 1. **Definition.**
  - 2. **Three Classes of Levers.**
    - (1.) ***First Class.***
    - (2.) ***Second Class***
    - (3.) ***Third Class.***
  - 3. **Law of Equilibrium.**
  - 4. **Steelyard.**
  - 5. **Compound Lever.**
- 2. THE WHEEL AND AXLE.
  - 1. **Definition and Illustration.**
  - 2. **Law of Equilibrium.**
  - 3. **Wheelwork.**
- 3. THE INCLINED PLANE.
  - 1. **Definition and Illustration.**
  - 2. **Law of Equilibrium.**
- 4. THE SCREW.
  - 1. **Definition and Illustration.**
  - 2. **Law of Equilibrium.**
- 5. THE WEDGE.
  - 1. **Definition and Illustration.**
  - 2. **Law of Equilibrium.**
- 6. THE PULLEY.
  - 1. **Definition and Illustration.**
  - 2. **Fixed and Movable Pulleys**
  - 3. **Combinations of Pulleys.**
  - 4. **Law of Equilibrium.**
- 7. CUMULATIVE CONTRIVANCES.
- 8. PERPETUAL MOTION.

ELEMENTS OF MACHINES.

The Simple Machines are the elements to which all machinery can be reduced. The watch with its complex system of wheel-work, and the engine with its belts, cranks and pistons, are only various modifications of some of the six elementary forms—the *lever,* the *wheel and axle,* the *inclined plane,* the *screw,* the *wedge,* and the *pulley.**

They are often termed the Mechanical Powers, but they do not produce work; they are only methods of applying it. Here again the doctrine of the Conservation of Energy holds good. The work done by the power is always equal to the resistance overcome in the weight.

The Law of Mechanics is, *the power multiplied by the distance through which it moves, is equal to the weight multiplied by the distance through which it moves.*† Ex.: 1 lb. of power moving through 10 feet = 10 lbs. of weight moving through one foot, or *vice versa.*

1. The Lever is a bar turning on a pivot. The force used is termed the *power* (P), the object to be lifted the *weight* (W), the pivot on which the lever turns the *fulcrum* (F), and the parts of the lever each side of the fulcrum the *arms.*

THREE CLASSES OF LEVERS.—In the three kinds, the fulcrum, weight and power are each respectively between the other two, as may be seen by comparing Figs. 39–41.

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* These six may be still further reduced to two — the lever and the inclined plane.

† In theory, the parts of a machine have no weight, move with no friction, and meet no resistance from the air. In practice, these influences must be considered.

Fig. 39.

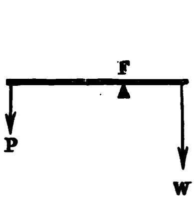


Fig. 40.

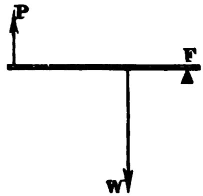
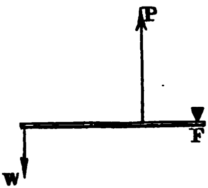
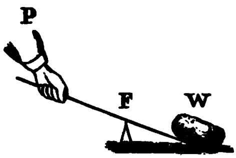


Fig. 41.



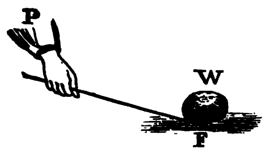
First Class.—We wish to lift a heavy stone. Accordingly we put one end of a handspike under it, and resting the bar on a block at F, bear down at P.—A pump-handle is a lever of the first class. The hand is the P, the water lifted the W, and the pivot the F.—A pair of scissors is a double lever of the same class. The cloth to be cut is the W, the hand the P, and the rivet the F.

Fig. 42.



Second Class.—We may also raise the stone, as in Fig. 43, by resting one end of the lever on the ground, which acts as a fulcrum, and lifting up on the bar.—An oar is a lever of the second class. The hand is the P, the boat the W, and the water the F.

Fig. 43.



Third Class.—The treadle of a sewing-machine is a lever of the third class. The front end resting on the ground is the F, the foot is the P, and the force is transmitted by a rod to the W, the arm above.—In the fishing-rod, one hand is the F, the other the P, and the fish the W.

Law of Equilibrium.—A force multiplied by its perpendicular distance from a point is called the *moment* or *turning effort* of the force about that point as a pivot. In the lever, P balances W when the moments about the fulcrum are equal. Let P*d* represent power's distance from

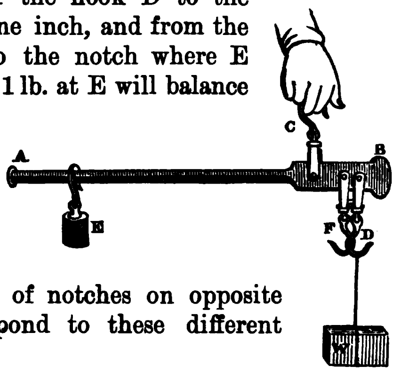
the F, and Wd weight's distance. Substituting these terms in the law of mechanics,

$$P \times Pd = W \times Wd \ (1). \qquad P : W :: Wd : Pd \ (2). \qquad P = \frac{W \times Wd}{Pd} \ (3).$$

In the first and second classes, as ordinarily used, we gain power and lose time; in the third class we lose power and gain time.

The STEELYARD is a lever of the first class. The P is at E, the F at C, and the W at D. If the distance from the pivot of the hook D to the pivot of the hook C be one inch, and from the pivot of the hook C to the notch where E hangs be 12 inches, then 1 lb. at E will balance 12 lbs. at W. If the steelyard be reversed (Fig. 45), then the distance of the F from the W is only $\frac{1}{4}$ as great, and 1 lb. at E will balance 48 lbs. at D. Two sets of notches on opposite sides of the bar correspond to these different positions.

FIG. 44.



The COMPOUND LEVER consists of several levers so connected that the short arm of the first acts on the long arm of the second, and so on to the last of the series. If the distance of A (Fig. 46) from the F be four times that of B, a P of 5 lbs. at A will lift a W of 20 lbs. at B. If the arms of the second lever are of the same comparative length, a P of 20 lbs. at C will lift 80 lbs. at E. In the third lever, a P of 80 lbs. at D will lift 320 lbs. at F. With this system of three levers, 5 lbs. at A will accordingly balance 320 lbs. at F. To raise

FIG. 45.

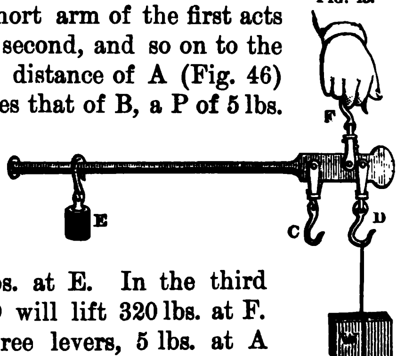
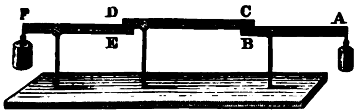


FIG. 46.



the W 1 foot, however, the P must move 64 feet. Thus what is gained in power is lost in time. There is no creation of force by the use of the levers; the rather, there is a small loss because of friction.

Hay scales are constructed upon the principle of the compound lever. The platform rests on several levers, as shown in Fig. 47. These are connected with a side lever, which is notched to indicate the pounds, etc. The weight is moved along this lever until it balances the load of hay.

FIG. 47.

2. The Wheel and Axle is a kind of perpetual lever. As both arms work continuously, we are not obliged to prop up the W and readjust the lever. In the windlass used for drawing water from a well, the P is applied at the handle, the W is the bucket, and the F is the axis of the windlass. The long arm of the lever is the length of the handle, and the short arm is the semi-diameter of the axle. This is shown in a cross-section (Fig. 48) where O

FIG. 48.

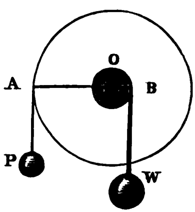


FIG. 49.

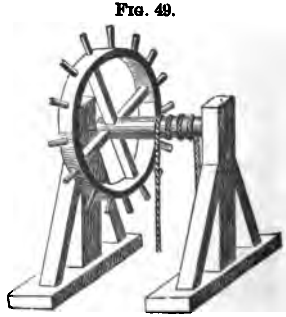
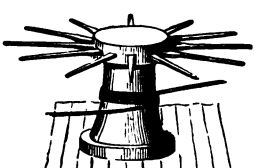
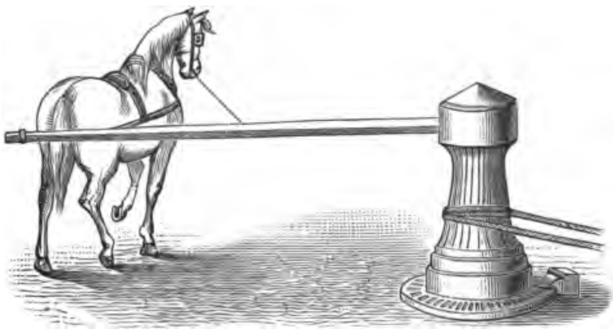


FIG. 50.



is the F, O A the long arm, and O B the short arm.—In Fig. 49, instead of turning a handle we take hold of pins inserted in the rim of the wheel.—Fig. 50 represents a capstan used on vessels for weighing the anchor. The P is applied by handspikes inserted in the axle.—Fig. 51 shows a form of the capstan employed in moving buildings, in which a horse furnishes the power.

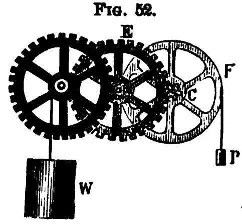
Fig. 51.



Law of Equilibrium.—By turning the handle or wheel around once, the rope will be wound around the axle and the W be lifted that distance. Applying the law of mechanics, P $\times$ the circumference of the wheel $=$ W $\times$ circumference of the axle; or, as circles are proportional to their radii,

$$P : W :: \text{radius of the axle} : \text{radius of the wheel}. \qquad (4.)$$

Fig. 52.

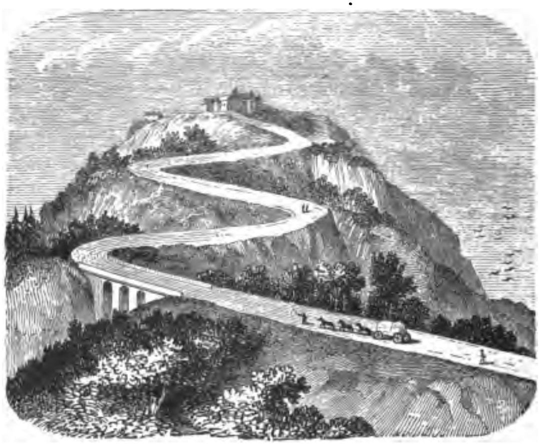


Wheelwork consists of a series of wheels and axles which act upon one another on the principle of the compound lever. The cogs on the circumference of the wheel are termed *teeth,* on the axle *leaves,* and the axle itself is called *a pinion.* If the radius of the wheel F be 12 inches, and that of the pinion 2 inches, then a P of 1 lb. will apply a

force of 6 lbs. to the second wheel E. If the radius of this be 12 inches, then the second wheel will apply a P of 36 lbs. to the third wheel, which, acting on its axle, will balance a W of 216 lbs.*

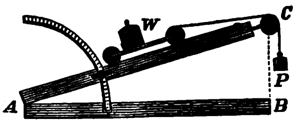
3. The Inclined Plane.—If we wish to lift a heavy cask into a wagon, we rest one end of a plank on the wagon-box and the other on the ground. We can then easily roll the cask up this inclined plane. When roads are to be made

FIG. 53.



over steep hills, they are sometimes constructed around the hill, like the thread of a screw, or in a winding manner as shown in Fig. 53.†

FIG. 54.



LAW OF EQUILIBRIUM.—In Fig. 54 the P must descend a distance CA to elevate the W to the height BC. Applying the law of mechanics, P ×

* The W will pass through only $\frac{1}{216}$ the distance of the P. We thus gain power and lose speed. If we wish to reverse this we can apply the P to the axle, and so gain speed. This is the plan adopted in factories, where a water-wheel furnishes abundant power, and spindles or other swift machines are to be turned with great rapidity.

† There is a remarkable ascent of this kind on Mount Royal, Montreal.

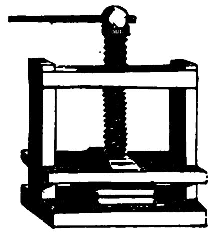
length of inclined plane = W × height of inclined plane; hence,

P : W : : height of inclined plane : length of inclined plane. * (5.)

If a road ascend 1 foot in 100 feet, then a horse drawing up a wagon has to lift only $\frac{1}{100}$ of the load, besides overcoming the friction. A body sliding down a smooth inclined plane acquires the same velocity that it would in falling the same height perpendicularly. A train descending a grade of 1 foot in 100 feet tends to go down with a force equal to $\frac{1}{100}$ of its weight.†

4. The Screw consists of an inclined plane wound around a cylinder, the former being called the *thread*, and the latter the *body*. It works in a *nut* which is fitted with reverse threads to move on the thread of the screw. The nut may turn on the screw, or the screw in the nut. The P may be applied to either, by means of a wrench or lever. The screw is used in vises; in raising buildings; in copying letters, and in presses for squeezing the juice from apples, sugar-cane, etc.

FIG. 55.



LAW OF EQUILIBRIUM.—When the P is applied at the end of a lever, it describes a circle of which the lever is the radius. The distance through which the P passes, is the circumference of this circle; and the height to which the W is elevated at each revolution of the screw, is the distance

* If we roll into a wagon a barrel of pork, weighing 200 lbs., up a plane 12 feet long and 3 feet high, we have x = 50 lbs. : 200 lbs. : : 3 feet : 12 feet. We lift only 50 lbs., or ¼ of the barrel, but we raise it through four times the space that would be necessary if we could elevate it directly into the wagon. We thus lose speed and gain power. The longer the inclined plane, the heavier the load we can lift, but the more time it will take to do it.

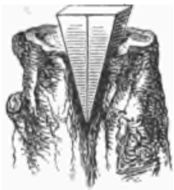
† Near Lake Lucerne is a forest of firs on the top of Mount Pilatus, an almost inaccessible Alpine summit. By means of a wooden trough, the trees are conducted into the water below, a distance of eight miles, in as many minutes. One standing near hears a roar as of distant thunder, and the next instant the descending tree darts past and plunges downward out of sight. The force with which it falls is so prodigious, that if it jumps out of the trough it is dashed to pieces.

between two of the threads. Applying the law of mechanics, P × circumference of circle = W × interval between the threads; hence,

P : W :: interval : circumference. (6.)

The efficiency of the screw may be increased by lengthening the lever, or by diminishing the distance between the threads.

FIG. 56.



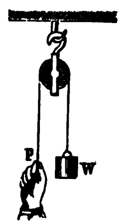
5. The Wedge consists generally of two inclined planes placed back to back. It is used for splitting wood and stone and lifting vessels in the dock. Leaning chimneys have been righted by wedges driven in on the lower side. Nails, needles, pins, knives, axes, etc., are made on the principle of the wedge.

The LAW OF EQUILIBRIUM is the same as that of the inclined plane—viz.,*

P : W :: thickness of wedge : length of wedge. (7.)

6. The Pulley consists of a wheel, within the grooved edge of which runs a cord.

FIG. 57.



A FIXED PULLEY (Fig. 57) merely changes the direction of the force. There is no gain of power or speed, as the hand P must move down as much as the weight W rises, and both with the same velocity. It is simply a lever of the first class with equal arms. By its use a man standing on the ground will hoist a flag to the top of a lofty pole, and thus avoid the trouble and danger of climbing up with it. Two fixed pulleys, arranged as shown in Fig. 58, enable a

FIG. 53.

* In practice, however, this by no means accounts for the prodigious power of the wedge. Friction, in the other mechanical powers, diminishes their efficiency; in

heavy load to be elevated to the upper story of a building by horse-power.

A Movable Pulley is represented in Fig. 59. One-half of the barrel is sustained by the hook while the hand lifts the other. As the P is one-half the W, it must move through twice the space; in other words, by taking twice the time, we can lift twice as much. Thus power is gained and time lost.

Fig. 59.

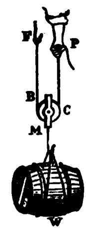
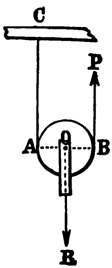


Fig. 60.



We may also explain the single movable pulley by Fig. 60. A represents the F, R the W acting in the line OR, and B the P acting in the line BP. This is a lever of the second class; and as AO = ½ AB, P = ½ W.

Combinations of Pulleys.—(1.) In Fig. 61, we have the W sustained by three cords, each of which is stretched by a tension equal to the P; hence 1 lb. of power will balance 3 lbs. of weight. (2.) In Fig. 62, the P will sustain a W of 4 lbs. (3.) In Fig. 63, the cord marked 1 1 has a tension equal to P in each part; the one marked 2 2 has a tension equal to 2P in each part, and so on with the others. The sum of the tensions acting on W is 16; hence W = 16 P.

Fig. 61.

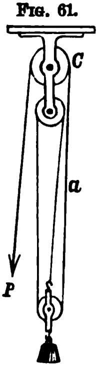


Fig. 62.

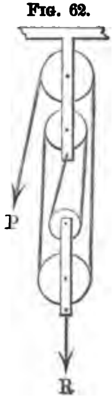
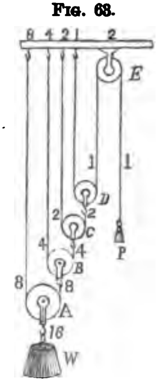


Fig. 63.



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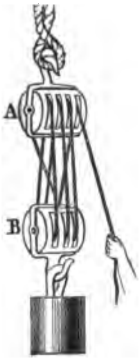
this it is essential, else the wedge would fly back and the effect be lost. In the others, the P is applied as a steady pressure; in this it is a sudden blow, and depends upon the striking force of the hammer.

In this system, D rises twice as fast as C, four times as fast as B, etc. Work must stop when D reaches E, which gives little sweep to A for lifting W. (4.) Fig. 64 represents the ordinary "tackle-block" used by mechanics.

FIG. 64.



LAW OF EQUILIBRIUM.—When a continuous rope is used, let n represent the number of separate parts of the cord which sustain the movable block. We then have

$$P = \frac{W}{n}. \qquad (8.)$$

When the number of movable and of fixed pulleys is equal, in general, W = P × twice the number of movable pulleys.

7. Cumulative Contrivances.—A hammer, club, pile-driver, sling, fly-wheel, etc., are instruments for accumulating energy to be used at the proper moment. Thus we may press a hammer on the head of a nail with all our strength to no purpose; but swing the hammer the length of the arm, and the blow will bury the nail to the head. The strength of our muscles and the attraction of gravity during the fall both gather force to be exerted at the instant of contact. A fly-wheel by its momentum equalizes an irregular force, or produces a sudden effect.*

8. Perpetual Motion.—It is impracticable to make a machine capable of perpetual motion. No combination can produce energy; it can only direct that which is applied. In all machinery there is friction; this must ultimately exhaust the power and bring the motion to rest. The only question is, how long time will be required for the leakage to drain the reservoir.

* We see the former illustrated in a sewing-machine, and the latter in a punch operated by a treadle. In the one case, the irregular action of the foot is turned into a uniform motion, and in the other it is concentrated in a heavy blow that will pierce a thick piece of metal.

PRACTICAL QUESTIONS.—1. Describe the rudder of a boat as a lever. A door. A door-latch. A lemon-squeezer. A pitchfork. A spade. A shovel. A sheep-shears. A poker. A pair of tongs. A balance. A pair of pincers. A wheelbarrow. A man pushing open a gate with his hand near the hinge. A sledge-hammer, when the arm is swung from the shoulder. A nut-cracker. The arm (see Physiology, p. 48). 2. Show the change that occurs from the second to the third class of lever, when you take hold of a ladder at one end and raise it against a building. 3. Why is a pinch from the tongs near the hinge more severe than one near the end? 4. Two persons are carrying a weight of 250 lbs., hanging between them from a pole 10 feet in length. Where should it be suspended so that one will lift only 50 lbs.? 5. In a lever of the first class, 6 feet long, where should the F be placed so that a P of 1 lb. will balance a W of 23 lbs.? 6. What P would be required to lift a barrel of pork with a windlass whose axle is 1 foot in diameter, and handle 3 feet long? 7. What sized axle, with a wheel 6 feet in diameter, would be required to balance a W of one ton by a P of 100 lbs.? 8. What number of movable pulleys would be required to lift a W of 200 lbs. by a P of 25 lbs.? 9. How many pounds could be lifted with a system of 4 movable pulleys by a P of 100 lbs.? 10. What W could be lifted with a single horse-power * acting on a system of pulleys shown in Fig. 64? 11. What distance should there be between the threads of a screw to enable a P of 25 lbs. acting on a handle three feet long, to lift a ton? 12. How high would a P of 12 lbs., moving 16 feet along an inclined plane, lift a W of 96 lbs.? 13. I wish to roll a barrel of flour into a wagon, the box of which is four feet from the ground. I can lift but 24 lbs. How long a plank must I get? 14. The "evener" of a pair of whiffletrees is 3 feet 6 inches in length; how much must the whiffletree be moved to give one horse an advantage of one-third over the other? 15. In a set of three-horse whiffletrees, having an "evener" 5 feet in length, at what point should the plough-clevis be attached that the single horse may draw the same as each of the span of horses? At what point to give him one-quarter "advantage"? 16. What W can be lifted with a P of 100 lbs. acting on a screw having threads 1 inch apart, and a handle 4 feet long? 17. What is the object of the balls often cast on the ends of the handle of the screw used in presses for copying letters? 18. In a steelyard 2 feet long, the distance from the weight-hook to the fulcrum-hook is 2 inches; how heavy a body can be weighed with a pound weight? 19. Describe the change from the first to the third class of lever, in the different ways of using a pitchfork or a spade. 20. Why are not blacksmiths' tongs and fire-tongs constructed on the same principle? 21. In a lever of the third class, what W will a P of 50 lbs. balance, if one arm be 12 feet and the other 3 feet long? 22. In a lever of the second class, what W will a P of 50 lbs. balance, with a lever 12 feet long, and the W 3 feet from the F? 23. In a lever of the first class, what W will a P of 50 lbs. balance, with a lever 12 feet long, and the F 3 feet from the W? 24. In a wheel and axle, the P = 40 lbs., the W = 360 lbs., and the diameter of the axle = 8 in. Required the circumference of the wheel. 25. Suppose, in a wheel and axle, the P = 20 lbs., the W = 240 lbs., and the diameter of the wheel = 4 feet. Required the circumference of the axle. 26. Required, in a wheel and axle, the diameter of the wheel, the diameter of the axle being 10 inches, the P 100 lbs., and the W 1 ton. 27. Why is the rim of a fly-wheel made so heavy? 28. Describe the hammer, when used in drawing a nail, as a *bent lever*, i. e., one in which the bar is not straight. 29. Describe the four levers shown in Fig. 27, when both the load of hay and the weight are considered, respectively, as the W and the P.

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* A *horse-power* is a force which is equivalent to 550 *foot-pounds*, i. e., can raise against gravity 550 lbs. one foot in one second, or 33,000 lbs one foot in one minute.

SUMMARY.

All machines can be resolved into one or more elementary forms. Of these there are six, viz., the lever, the wheel and axle, the inclined plane, the screw, the wedge and the pulley. Though called the mechanical powers, they are only instruments by which we can avail ourselves of the forces of nature. Molar energy or the motion of masses, as of air, water, steam, etc., is thus utilized, while the strength of a horse does the work of many men. A force of small intensity made to act through a considerable distance becomes one of great intensity acting through a small distance, and *vice versa*. No machine is a source of power, but in all cases $P \times Pd = W \times Wd$. The law of energy thus forbids perpetual motion. The lever is a bar resting at some part on a prop as a centre of motion. To this simple machine may be reduced also the wheel and axle, and the pulley. The crow-bar, claw-hammer for drawing nails, pincers, windlass and steelyard are examples of the various classes of levers. To the inclined plane may be reduced also the wedge and the screw. The laws of falling bodies obtain so that on a plane sloping one foot in sixteen a body (neglecting friction) would descend only one foot in the first second. The awl, vise, carpenter's plane, corkscrew, tackle-block and stairs are common modifications of the inclined plane.

HISTORICAL SKETCH.

Simple machines for moving large bodies are as old as history. The Babylonians knew the use of the lever, the pulley and the roller. The Romans were acquainted with the lever, the wheel and axle, and the pulley (simple and compound). The Egyptians, it is thought, raised the immense stones used in building the Pyramids, by inclined planes made of earth which was afterward removed. Archimedes in the 3d century B. C., discovered the law of equilibrium in the lever.* His investigations, however, were too far in advance of his time to be fully understood, and the teachings of Aristotle were long after accepted by scientific men. The law of mechanics or of Virtual Velocity, as it is called, was discovered by Galileo.

* It is often said that Archimedes, in allusion to the tremendous power of the lever, asserted that, Give him a fulcrum and he could move the world. Had he been allowed such a chance, "the fulcrum being nine thousand leagues from the centre of the earth, with a power of 200 lbs. the geometer would have required a lever 12 quadrillions of miles long and the power would have needed to move at the rate of a cannon-ball to lift the earth one inch in 27 trillions of years."

V.

PRESSURE OF LIQUIDS AND GASES.

" *The waves that moan along the shore,*
The winds that sigh in blowing,
Are sent to teach a mystic lore
Which men are wise in knowing."

ANALYSIS.

PRESSURE OF LIQUIDS AND GASES.

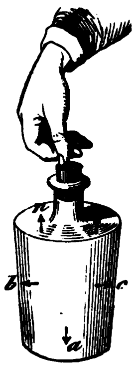
- **I. HYDROSTATICS.**
  - 1. LIQUIDS INFLUENCED BY EXTERNAL PRESSURE ONLY.
    - (1.) Law of Transmission.
    - (2.) Water as a Mechanical Power.
    - (3.) Hydrostatic Press.
  - 2. LIQUIDS INFLUENCED BY GRAVITY.
    - (1.) Four Laws of Equilibrium.
    - (2.) Rules for Computing Pressure.
    - (3.) Water Level.
      - (a.) *Definition and illustration.*
      - (b.) *Buoyant force of liquids.*
    - (4.) Specific Gravity.
      - (c.) *To find specific gravity of a solid.*
      - (d.) *To find specific gravity of a liquid.*
      - (e.) *To find weight of given bulk.*
      - (f.) *To find bulk of given weight.*
      - (g.) *To find vol. of a body.*
      - (h.) *Floating bodies.*
- **II. HYDRAULICS.**
  - —DEFINITION AND GENERAL PRINCIPLES.
  - 1. RULES CONCERNING A JET.
    - (1.) The velocity that of a falling body.
    - (2.) To find the velocity.
    - (3.) To find the quantity.
  - 2. EFFECT OF TUBES.
  - 3. FLOW OF WATER IN RIVERS.
  - 4. WATER-WHEELS.
    - (1.) Overshot.
    - (2.) Undershot.
    - (3.) Breast.
    - (4.) Turbine.
  - 5. WAVES.
- **III. PNEUMATICS.**
  - —DEFINITION AND GENERAL PRINCIPLES.
  - 1. AIR PUMP.
  - 2. CONDENSER.
  - 3. PROPERTIES OF AIR.
    - (1.) Weight.
    - (2.) Elasticity
    - (3.) Expansibility.
  - 4. PRESSURE OF THE AIR.
    - (1.) The Proof.
    - (2.) Upward Pressure.
    - (3.) Buoyant Force.
    - (4.) Amount of Pressure.
    - (5.) Pressure Varies.
    - (6.) Mariotte's (or Boyle's) Law.
    - (7.) Barometer.
  - 5. PUMPS.
    - (1.) Lifting.
    - (2.) Forcing.
    - (3.) Fire-engine.
  - 6. SIPHON.
  - 7. PNEUMATIC INKSTAND.
  - 8. HYDRAULIC RAM.
  - 9. ATOMIZER.
  - 10. HEIGHT OF THE AIR.

I. HYDROSTATICS.

Hydrostatics treats of liquids at rest. Its principles apply to all liquids; but water, on account of its abundance, is taken as the type.

1. Liquids Influenced by External Pressure only.—(1.) LIQUIDS TRANSMIT PRESSURE EQUALLY IN ALL DIRECTIONS. As the particles of a liquid move freely among themselves, there is no loss by friction, and any force will be transmitted equally upward, downward, and sidewise. Thus if a bottle be filled with water and a pressure of 1 lb. be applied upon the cork, it will be communicated from particle to particle throughout the water. If the area of the cork be one square inch, the pressure upon any square inch of the glass at *n, a, b,* or *c,* will be 1 lb. If the inside surface of the bottle be 100 square inches, a pressure of 1 lb. upon the cork will produce a force of 100 lbs., tending to burst the bottle.

FIG. 65.



Illustrations.—The transmission of pressure by liquids under some circumstances, is more perfect than by solids. Let a straight tube, AB, be filled with a cylinder of lead, and a piston be fitted to the end of the tube. If a force be applied at P it will be transmitted to O without loss. If instead, we use a bent tube, the force will be transmitted in the lines of the arrows, and will act on P but slightly. If, however, we fill the

FIG. 66.

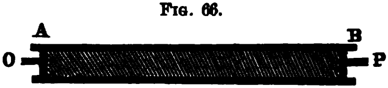
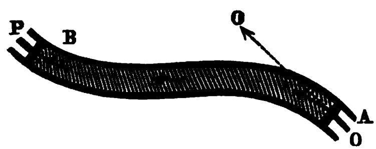
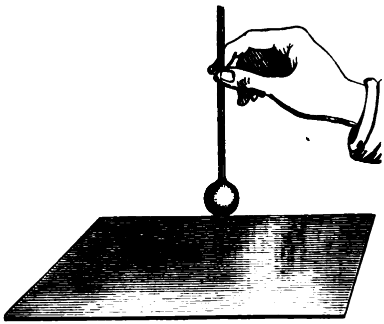


FIG. 67.



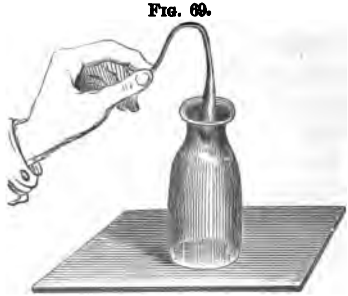
tube with water, the force will pass without diminution.* Take a glass bulb and stem full of water, as in Fig. 68.† If you are careful to let the stem slip loosely through your fingers as the bulb strikes, you may pound it upon a smooth surface with all your strength. The force of the blow being instantly transmitted from the thin glass to the water, which is almost incompressible, makes the bulb nearly as solid as a ball of iron.

FIG. 68.



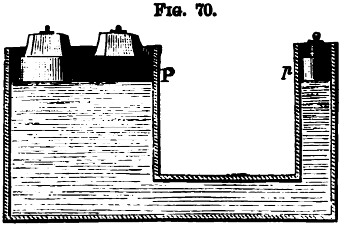
If a Rupert's drop be held in a vial of water so as not to touch the glass (Fig. 69), and the tapering end be broken, the water will transmit the concussion and shatter the vial.

FIG. 69.



(2.) WATER AS A MECHANICAL POWER.—Take two cylinders, P and p, (Fig. 70) fitted with pistons and filled with water. Let the area of p be 2 inches and that of P be 100 inches. Then, according to the principle of the equal pressure of liquids, a downward pressure of 1 lb. on each square inch of the small piston will produce an upward pressure of 1 lb.

FIG. 70.



* With cords, pulleys, levers, etc., we always lose about one-half of the force by friction ; but this "liquid rope" transmits it with no appreciable loss.

† The process of filling such bulbs is shown on p. 186. They are cheaply pur-

on each square inch of the large piston. Hence a P of 2 lbs. will lift a W of 100 lbs.*

(3.) THE HYDROSTATIC, OR HYDRAULIC PRESS (Fig. 71) utilizes the principle just explained. As the workman de-

FIG. 71.

presses the lever O, he forces down the piston *a* upon the water in the cylinder A. The pressure is transmitted

chased of apparatus dealers and explain not only this point but also the method of filling thermometers.

* Pascal announced the discovery of this principle in the following words, "If a vessel full of water closed on all sides has two openings, the one a hundred times as large as the other, and if each be supplied with a piston which fits exactly, a man pushing the small piston will exert a force which will balance that of a hundred men pushing the large one."

through the bent tube of water *d* under the piston C, which lifts up the platform K, and compresses the bales. If the area of *a* be 1 inch and that of C 100 inches, a force of 100 lbs. will lift 10,000 lbs. Still farther to increase the efficiency of this press, the handle is a lever of the second class. If the distance of the hand from the pivot be ten times that of the piston, a P of 100 lbs. will produce a force of 1,000 lbs. at *a*. This will become 100,000 lbs. at C.* According to the principle of mechanics, $P \times Pd = W \times Wd$, the platform will ascend $\frac{1}{1000}$ of the distance the hand descends. This machine is used for baling hay and cotton, for launching vessels, and for testing the strength of ropes, chains, etc.

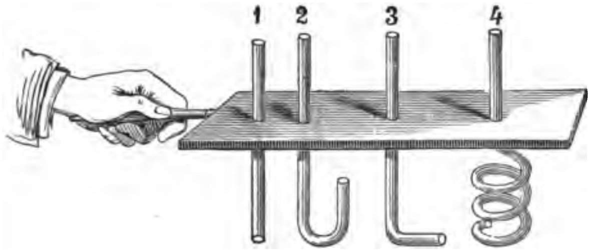
2. Liquids Influenced by Gravity.—The lower part of a vessel of water must bear the weight of the upper part. Thus each particle of water at rest is pressed downward by the weight of the minute column it sustains. It must, in turn, press in every direction with the same force, else it would be driven out of its place and the liquid would no longer be at rest. Indeed, when a liquid is disturbed it comes to rest—*i. e.*, there is an equilibrium established—only when this equality of pressure is produced. In consequence of this constant pressure the following laws obtain:

(1.) FOUR LAWS OF EQUILIBRIUM.—I. *Liquids at rest press downward, upward and sidewise with the same force.* If the series of glass tubes shown in Fig. 72 be placed in a pail of water, the liquid will be forced up 1 by the upward pressure of the water, 2 by the downward pressure, 3 by the lateral pressure, and 4 by the three combined in different portions of the tube. The water will rise in them all to the same height—*i. e.*, to the level of the water in the pail.

---

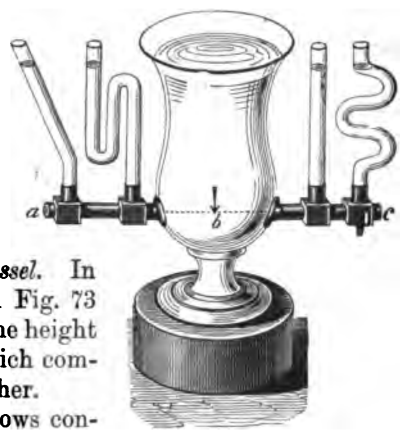
* The presses employed for raising the immense tubes of the Britannia Bridge across the Menai Strait, were each capable of lifting 2,672 tons, and of "throwing water in a vacuum to a height of nearly six miles, or over the top of the highest mountain." The difference between *a* and C may be increased until the weight of a girl's hand would lift a man-of-war.

FIG. 72.



II. *The pressure increases with the depth.* The pressure per square foot at the depth of 1 foot is the weight of a cubic foot of water—viz., about 62½ lbs. (1,000 ozs.); at 2 feet, twice that amount; and so on. In sea-water it is greater, as that weighs 64.37 lbs. per cubic foot. At great depths this pressure becomes enormous. If a square glass bottle, empty and firmly corked, be sunk into the water, it will generally be crushed before sinking ten fathoms. When a ship founders at sea, the water is forced into the pores of the wood, so that no part can ever rise again to the surface to reveal the fate of the lost vessel.

FIG. 73.



III. *The pressure does not depend on the shape or size of the vessel.* In the apparatus shown in Fig. 73 the water rises to the same height in the various tubes, which communicate with one another.

The Hydrostatic Bellows consists of two boards, each hinged on one side and resting on a rubber bag, to which is attached an upright tube, A. Water is poured in at A until

the bag and the tube are filled. The pressure of the column of water in the tube lifts the weights hung by crossbars beneath. It will make no difference in the weight supported, whether we use A or B, although the former holds ten times as much water as the latter. C, however, being longer, the water will exert a greater pressure. Another form of the apparatus (Fig. 75) consists of two boards connected by a band of leather, in which a tall tube A is inserted. If this be filled with water, the pressure will lift a weight as much greater than the weight of the water in the tube as the area of the bellows-board is greater than that of the tube. Applying the law of mechanics, if 1 oz. of water raise a weight of 50 ozs. 1 inch, the water must fall 50 inches.

FIG. 74.

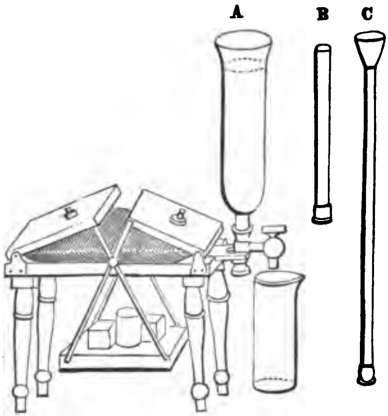


FIG. 75.

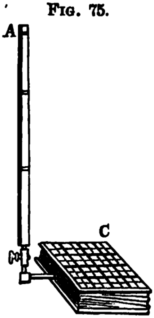


FIG. 76.

A strong cask fitted with a small pipe 30 or 40 feet long, if filled with water will be burst asunder.* The

* Suppose the pipe to have an area of $\frac{1}{40}$ square inch, and to hold ½ lb. of water. The pressure on each $\frac{1}{40}$ of an inch of the interior of the cask would be ½ lb., or 2880 lbs. on each square foot—a pressure no common barrel could sustain.

pressure is as great as if the tube were of the same diameter as the cask. In a coffee-pot the small quantity of liquid in the spout balances the large quantity in the vessel. If it were not so, it would rise in the spout and run out.*

IV. *Water seeks its level.* In Fig. 77 a tank is situated on a hill, whence the water is conducted underground through

FIG. 77.

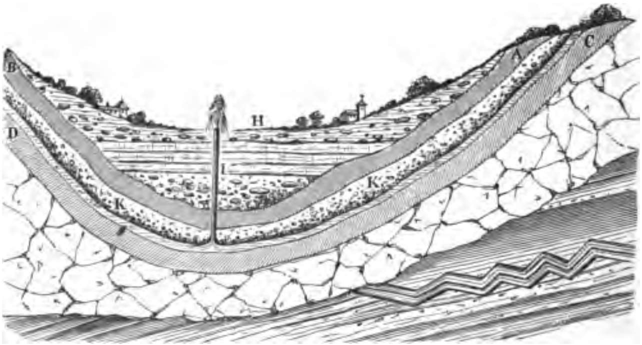
a pipe to the fountain. In theory the jet will rise to the level of the reservoir, but in practice it falls short, owing to the friction at the nozzle of the pipe and in passing through the air, and the weight of the falling drops.

Artesian Wells.†—Let A B and C D represent curved strata of clay impervious to water, and K K a layer of gravel. The rain falling on the hills filters down to C D,

* The principle that a small quantity of water will thus balance another quantity, however large, or will lift any weight, however great, is frequently termed the "Hydrostatic Paradox." It is only an instance of a general law, and is no more paradoxical than the action of the lever.

† They are so named because they have long been used in the province of Artois (Latin, Artesium), France. They were, however, early employed by the Chinese for the purpose of procuring gas and salt water.

FIG. 78.



and collects in this basin. If a well be bored at H, as soon as it reaches the gravel the water will rush upward, under the tremendous lateral pressure, to the height of the source, often spouting high in air.*

Wells.—Of the rain which falls on the land, a part runs directly to the streams and part soaks into the soil. The latter portion may filter down to an impermeable layer of rock or clay, and then run along till it oozes out at some lower point as a spring; or, if it cannot escape, it will collect in the ground. If a well be sunk into this subterranean reservoir, the water will rise in it to the level around.†

(2.) RULES FOR COMPUTING PRESSURE.—I. *To find the pressure on the bottom of a vessel.* Multiply the area of the

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* The famous well at Grenelle, Paris, is at the bottom of a basin which extends miles from the city. It is about 1,800 feet deep, and furnishes 656 gallons of water per minute. The two wells of Chicago are about 700 feet deep, and discharge daily about 432,000 gallons. Being situated on the level prairie, the force with which the water comes to the surface indicates that it is supplied perhaps from Rock River, 100 miles distant. There are also valuable artesian wells at Louisville, Kentucky, and at Charleston, South Carolina. When the water comes from a great depth it is generally warm. (See *Geology*, p. 21.)

† "From a forgetfulness of this principle the company which dug the Thames and Medway Canal, England, incurred heavy damages. Having planned the canal to be filled at high tide, the salt water spread immediately into all the wells of the surrounding region. Had the canal been dug a few feet lower, the evil would have been avoided."—*Arnott.*

base by the perpendicular height, and that product by the weight of a cubic foot of the liquid.

II. *To find the pressure on the side of a vessel.* Multiply the area of the side by half of the perpendicular height,* and that product by the weight of a cubic foot of the liquid. The pressure on the bottom of a cubical vessel of water is

FIG. 79.

the weight of the water; on each side, one-half; and on the four sides, twice the weight; therefore, on the five sides the pressure is three times the weight of the water.

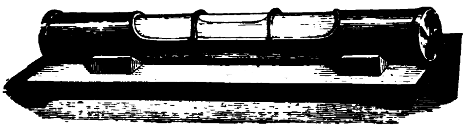
(3.) WATER-LEVEL.—The surface of standing water is said to be level—*i. e.*, horizontal to a plumb-line. This is true for small sheets of water, but for larger bodies an allowance must be made for the circular form of the earth (Fig. 79). The curvature is 8 inches per mile, and increases as the square of the distance.†

* This clause of the rule holds only when the centre of gravity of the side is at half the perpendicular height. In general, the depth of its centre of gravity below the surface should be used as the multiplier.

† For two miles it is 8 inches $\times 2^2 = 32$ inches. If one's eye were at the level of the water, he could see an object 66 feet high at a distance of 10 miles.

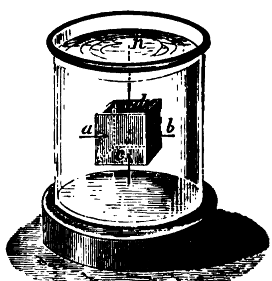
The *spirit-level* is an instrument used by builders for levelling. It consists of a slightly-curved glass tube so nearly full of alcohol that it holds only a bubble of air. When the level is horizontal, the bubble remains at the centre of the tube.

FIG. 80.



(4.) SPECIFIC GRAVITY, or relative weight, is the weight of a substance compared with that of the same bulk of another substance. It shows the relative mass or the density of a body. Water is taken as the standard* for solids and liquids, and air for gases.

FIG. 81.



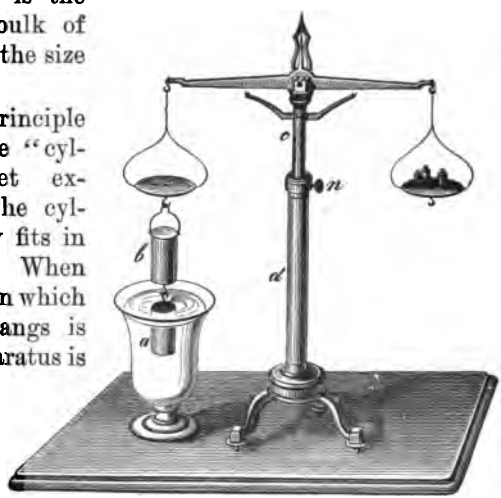
A cubic inch of sulphur weighs twice as much as a cubic inch of water; hence its specific gravity = 2. A cubic inch of carbonic-acid gas weighs 1.52 times as much as the same volume of air; hence its specific gravity = 1.52.

Buoyant Force of Liquids.—The cube *a b c d* is immersed in water. The lateral pressure at *a* is equal to that at *b*, because both sides are at the same depth; hence the body has no tendency toward either side of the jar. The upward

* The water must be at 39.2° F., its greatest density. In all exact measurements, especially of standards, it is necessary to know the temperature. For the scale that is a foot long to-day may be more or less than a foot long to morrow; the measure that holds a pint to-day may hold more or less than a pint to-morrow. Nay, more, these measures may not be the same in two consecutive moments. When a carpenter takes up his rule and applies it to some object, the size of which he wishes to determine, it becomes in that instant longer than it was before; when a druggist grasps his measuring glass in his hand to dispense some of his preparations, the glass increases in size. A person enters a cool room, and at once it becomes more capacious, for its walls, ceiling and floor, because of the heat he imparts, immediately expand.—*Draper.*

pressure at *c* is greater than the downward pressure at *d*, because its depth is greater; hence the cube has a tendency to rise. This upward pressure is called the buoyant force of the water. *It is equal to the weight of the liquid displaced.* For the downward pressure at *d* is the weight of a column of water whose area is that of the top of the cube, and whose perpendicular height is *n d*, and the upward pressure at *c* is equal to the weight of a column of the same size whose perpendicular height is *c n*. The difference between the two, or the buoyant force, is the weight of a bulk of water equal to the size of the cube.

Fig. 82.



The same principle is shown in the "cylinder-and-bucket experiment." The cylinder *a* exactly fits in the bucket *b*. When the glass vessel in which the cylinder hangs is empty, the apparatus is balanced by weights placed in the scale-pan. Next, water is poured into the glass vessel. Its buoyant force raises the cylinder and depresses the opposite scale-pan. Then water is dropped into the bucket; when it is exactly full, the scales will balance again. This proves that "a body in water is buoyed up by a force equal to the weight of the water it displaces."—*Archimedes' law*, p. 119.

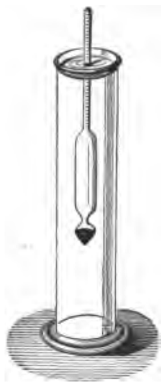
To find the specific gravity of a solid. Weigh the body in air, and in water; the difference is the weight of its bulk of water; divide its weight in air by its loss of weight in

water; the quotient is the specific gravity. Thus, sulphur loses one-half its weight when immersed in water; hence it is twice as heavy as water, and its specific gravity = 2.*

To find the specific gravity of a liquid by the specific-gravity flask. This is a bottle which holds exactly 1,000 grains of water. If it will hold 1,840 grains of sulphuric acid, the specific gravity of the acid is 1.84.

To find the specific gravity of a liquid by a hydrometer. This instrument consists of a glass tube, closed at one end and having at the other a bulb containing mercury. A graduated scale is marked upon the tube.

FIG. 83.



The *alcoholmeter*, used in testing alcohol, is so balanced as to sink in pure water to the zero point. As alcohol is lighter than water, the instrument will descend for every addition of spirits. The degrees of the scale indicate the percentage of alcohol. Similar instruments are used for determining the strength of milk, acids, etc.

To find the weight of a given bulk of any substance. Multiply the weight of one cubic foot of water by the specific gravity of the substance, and that product by the number of cubic feet. Ex.: What is the weight of three cubic feet of cork? *Solution:* 1,000 ozs. × .240† = 240 ozs.; 240 ozs. × 3 = 720 ozs.

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* If the body will not sink in water attach it to a heavy body. 1. Weigh the lighter body in air (A). 2. Weigh the heavy body in water (B). 3. Weigh both together in water (C). Now C is less than B because the light body buoys up the heavy one; *i. e.*, all its downward weight A is lost, and is actually converted into an upward or lifting force $= B - C$. Therefore the loss of the light body in water $= A + B - C$ $\therefore$ spec. grav. $= \dfrac{A}{A+B-C}$.

† TABLE OF SPECIFIC GRAVITY. (See Chem., p. 288.)

Iridium	21.80	Zinc	7.15	Pine Wood	.66
Platinum	21.53	Diamond ...about	3.50	Cork	.24
Gold	19.34	Flint Glass	2.76	Sulphuric Acid	1.84
Mercury	13.59	Chalk	2.65	Water from Dead Sea.	1.24
Lead	11.36	Sulphur	2.00	Milk	1.03
Silver	10.50	Ice	.93	Sea-water	1.03
Copper	8.90	Potassium	.86	Absolute Alcohol	.79
Cast-iron	7.21	Quicklime	.80		

To find the bulk of a given weight of any substance. Multiply the weight of a cubic foot of water by the specific gravity of the substance, and divide the given weight by that product. The quotient is the required bulk in cubic feet. Ex.: What is the bulk of 20,000 ozs. of lead? *Solution:* 1,000 ozs. $\times$ 11.36 = 11,360; 20,000 $\div$ 11,360 = 1.76 + cu. ft.

To find the volume of a body. Weigh it in water. The loss of weight is the weight of the displaced water. Then, as a cubic foot of water weighs 1,000 ozs., we can easily find the bulk of water displaced. Ex.: A body loses 10 ozs. on being weighed in water. The displaced water weighs 10 ozs. and is $\frac{1}{100}$ of a cubic foot; this is the exact volume of the body.

Floating Bodies.—A body will float in water when its weight is not greater than that of an equal bulk of the liquid, and its weight always equals that of the fluid displaced. An egg dropped into a glass jar half-full of water (Fig. 84) sinks directly to the bottom. If, by means of a funnel with a long tube, we pour brine beneath the water, the egg will rise. We may vary the experiment by not dropping in the egg until we have half filled the jar with the brine. The egg will then fall to the centre, and there float. Almost any solid if dissolved in water fills the pores of the water without adding to its bulk. This increases its density and buoyant power. A person can therefore swim more easily in salt than in fresh water.*—An iron ship will not only float itself, but also carry a

FIG. 84.

* Bayard Taylor says that he could float on the surface of the Dead Sea, with a log of wood for a pillow, as comfortably as if lying on a spring mattress. Another traveller remarks, that on plunging in he was thrown out again like a cork; and that on emerging and drying himself, the crystals of salt which covered his body made him resemble an "animated stick of rock-candy."

heavy cargo, because it displaces a great bulk of water.—A body floating in water has its centre of gravity at the lowest point, when it is in stable equilibrium.*—Fishes have air-bladders, by which they can rise or sink at pleasure.†

PRACTICAL QUESTIONS.—1. Why can housekeepers test the strength of lye, by trying whether or not an egg will float on it? 2. How much water will it take to make a gallon of strong brine? 3. Why can a fat man swim easier than a lean one? 4. Why does the firing of a cannon sometimes bring to the surface the body of a drowned person? *Ans.* Because by the concussion it shakes the body loose from the mud or any object with which it is entangled. 5. Why does the body of a drowned person generally come to the surface of the water, after a time? *Ans.* Because the gases which are generated by decomposition in the body render it lighter. 6. If we let bubbles of air pass up through a glass of water, why will they become larger as they ascend? 7. What is the pressure on a lock-gate 14 feet high and 10 feet wide, when the lock is full of water? 8. Will a pail of water weigh any more with a live fish in it than without? 9. If the water filtering down through a rock should collect in a crevice an inch square and 250 feet high, opening at the bottom into a closed fissure having 20 square feet of surface, what would be the total pressure tending to burst the rock? 10. Why can stones in water be moved so much more easily than on land? 11. Why is it so difficult to wade in water when there is any current? 12. Why is a mill-dam or canal embankment small at the top and large at the bottom? 13. In digging canals and building railroads, ought not the engineer to take into consideration the curvature of the earth? 14. Is the water at the bottom of the ocean denser than at the surface? 15. Why does the bubble of air in a spirit-level move as the instrument is turned? 16. Can a swimmer tread on pieces of glass at the bottom of the water more safely than on land? 17. Will a vessel draw more water in a river than in the ocean? 18. Will iron sink in mercury? 19. The water in the reservoir in New York is about 80 feet above the fountain in the City Hall Park. What is the pressure upon a single inch of the pipe at the latter point? 20. Why does cream rise on milk? 21. If a ship founder at sea, to what depth will it descend?‡ 22. There is a story told of a Chinese boy who accidentally dropped his ball into a deep hole where he could not reach it. He filled the hole with water, but the ball would not quite float. He finally thought of a successful expedient. Can you guess it? 23. Which has the greater buoyant force, water or oil? 24. What is the weight of four cubic feet of cork? 25. How many ounces of iron will a cubic foot of cork float in water? 26. What is the specific gravity of a body whose weight in air is 30 grs. and in water 20 grs.? How much is it heavier than water? 27. Which is heavier,

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* Herschel tells an amusing story of a man who attempted to walk on water by means of bulky cork boots. Scarcely, however, had he ventured out ere the law of gravitation seized him, and all that could be seen was a pair of heels, whose movements manifested a great state of uneasiness in the human appendage below.

† It was formerly thought that a fish in water has no weight. It is said that Charles II. of England once asked the philosophers of his time to explain this phenomenon. They offered many wise conjectures, but no one thought of trying the experiment. At last a simple-minded man balanced a vessel of water, and on adding a fish, found it weighed just as much as if placed on a dry scale-pan.

‡ It is a poetical thought that ships may thus sink into submarine currents and be carried hither and thither with their precious cargoes of freight and passengers, on voyages that know no end and toward harbors that they never reach.

a pail of fresh or one of salt water? 28. The weights of a piece of syenite-rock in air and water were 3941.8 grs. and 2607.5 grs. Find its specific gravity. 29. A specimen of green sapphire from Siam weighed in air 21.45 grs. and in water 16.33 grs.; required its specific gravity. 30. A specimen of granite weighs in air 534.8 grs. and in water 334.6 grs.; what is its specific gravity? 31. What is the bulk of a ton of iron? A ton of gold? A ton of copper? 32. What is the weight of a cube of gold 4 feet on each side? 33. A cistern is 12 feet long, 6 feet wide, and 10 feet deep; when full of water, what is the pressure on each side? 34. Why does a dead fish always float on its back? 35. A given bulk of water weighs 62.5 grs. and the same bulk of muriatic acid 75 grs. What is the specific gravity of the acid? 36. A vessel holds 10 lbs. of water; how much mercury would it contain? 37. A stone weighs 70 lbs. in air and 50 in water; what is its bulk? 38. A hollow ball of iron weighs 10 lbs.; what must be its bulk to float in water? 39. Suppose that Hiero's crown was an alloy of silver and gold, and weighed 22 ozs. in air and 20¾ ozs. in water. What was the proportion of each metal? 40. Why will oil, which floats on water, sink in alcohol? 41. A specific gravity bottle holds 100 gms. of water and 180 gms. of sulphuric acid. Required the density of the acid. 42. What is the density of a body which weighs 58 gms. in air and 46 gms. in water? 43. What is the density of a body which weighs 63 gms. in air and 35 gms. in a liquid of a density of .85?

II. HYDRAULICS.

Hydraulics treats of liquids in motion. In this, as in Hydrostatics, water is taken as the type. In theory, its principles are those of falling bodies, but in practice they cannot be relied upon except when verified by experiment. The discrepancy arises from changes of temperature which vary the fluidity of the liquid, from friction, the shape of the orifice, etc.

1. Rules Concerning a Jet.—(1.) THE VELOCITY OF A JET IS THE SAME AS THAT OF A BODY FALLING FROM THE SURFACE OF THE WATER. We can see that this must be so, if we recall two principles: First, "a jet will rise to the level of its source;" and second, "to elevate a body to any height, it must have the same velocity that it would acquire in falling that distance." It follows that the velocity of a jet depends on the height of the liquid above the orifice.

(2.) TO FIND THE VELOCITY OF A JET OF WATER, use the 8th equation of falling bodies, $V = \sqrt{2\,gd}$, in which d is

the distance of the orifice below the surface of the water. Ex.: The depth of water above the orifice is 64 feet; required the velocity. Substituting, $V = \sqrt{2 \times 32 \times 64} = 64$ feet.

(3.) TO FIND THE QUANTITY OF WATER DISCHARGED IN A GIVEN TIME, multiply the area of the orifice by the velocity of the water, and that product by the number of seconds. Ex.: What quantity of water will be discharged in 5 seconds from an orifice having an area of $\frac{1}{2}$ sq. foot, at a depth of 16 feet? At that depth, $V = \sqrt{2 \times 32 \times 16} = 32$ feet per second; multiplying by $\frac{1}{2}$, we have 16 cubic feet discharged in one second and 80 cubic feet in five seconds.* In practice about $\frac{5}{8}$ of this can be realized.

2. Effect of Tubes.—If we examine a jet of water, we see its size is decreased just outside the orifice to about two-thirds that at the opening. This neck is called the *vena contracta,* and is caused by the water producing cross currents as it flows from different directions toward the orifice. If a tube of a length twice or thrice the diameter of the opening be inserted, the water will adhere to the sides so that there will be no contraction, and the flow be increased to about 80 per cent. of the theoretical amount. If the tube be conical, and inserted with the large end inward, the discharge may be augmented to 95 per cent.; and if the outer end be flaring, it will reach 98 per cent. Long tubes or short angles, by friction, diminish the flow of water. It is said that an inch pipe 200 feet long will discharge only $\frac{1}{4}$ as much as a very short pipe of the same size.

3. Flow of Water in Rivers.—A fall of three inches per mile is sufficient to give motion to water, and produce a velocity of as many miles per hour. The Ganges descends but 800 feet in 1,800 miles. Its waters require a month to

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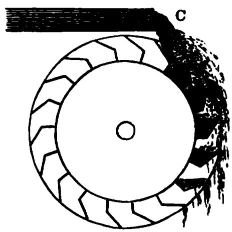
* If, at a foot below the surface, an opening will furnish 1 gallon per minute, to double that quantity the opening must be 4 feet below the top. Again, if a certain power will force through a nozzle of a fire-engine a given quantity of water in a minute, to double the quantity the power must be quadrupled (p. 36).

move down this long inclined plane.* A fall of 3 feet per mile will make a mountain torrent. The current moves more swiftly at the centre than near the shores or bottom of a channel, since there is less friction.

4. Water-wheels are machines for using the force of falling water. By bands or cog-wheels the motion of the wheel is conducted from the axle into the mill.†

The OVERSHOT-WHEEL has on its circumference a series of buckets which receive the water flowing from a *sluice*, C. These hold the water as they descend on one side, and empty it as they come up on the other. Overshot-wheels are valuable where a great fall can be secured, since they require but little water. If P denotes the weight of the water and d the distance it falls, then the total work $= Pd$. Of this amount 75 per cent. can be made available.

FIG. 85.



The UNDERSHOT-WHEEL has projecting boards or *floats*, which receive the force of the current. It is of use where there is little fall and a large quantity of water. It utilizes about 25 per cent. of the force.

FIG. 86.

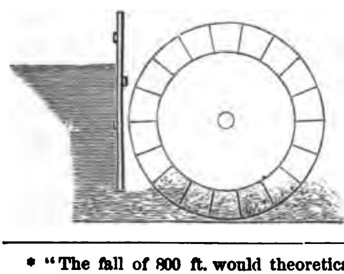
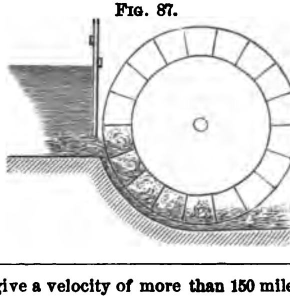


FIG. 87.



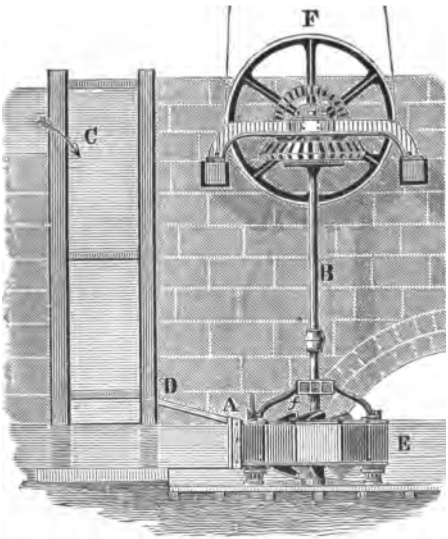
* "The fall of 800 ft. would theoretically give a velocity of more than 150 miles per hour. This is reduced by friction to about 3 miles."

† The principle is that of a lever with the P acting on the short arm. In this way the movement of the slow creaking axle reappears in the swiftly buzzing saw or flying spindle (p. 78).

The BREAST-WHEEL (Fig. 87) is a medium between the two kinds already named.

The TURBINE-WHEEL is placed horizontally and immersed in the water. In Fig. 88, C is the dam and DA the spout by which the water is furnished. E is a scroll-like casing encircling the wheel, and open at the centre above and below. The axis of the wheel is the cylinder *f*, from which radiate plane-floats against which the water strikes. To confine the water at the top and the bottom, is a circular disk attached to the cylinder and the floats. In these disks are the swells projecting above and below for discharging the water. They commence near the cylinder, and swelling outward scroll-shaped, form openings curved toward the cylinder, thus emptying the water in a direction opposite to that in which it enters the wheel. This form utilizes as high as 90 per cent. of the force. F is a band-wheel which conducts the power to the machinery.

FIG. 88.

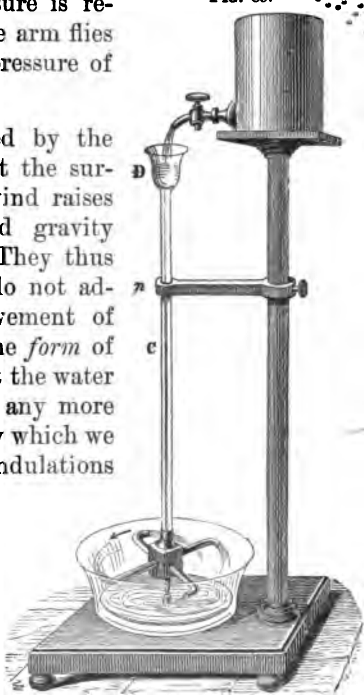


The principle of the *unbalanced pressure of a column of water* may also be employed. It is illustrated in the old-fashioned Barker's Mill or Reaction-Wheel.* This consists of an upright cylinder with horizontal arms, on the opposite

* Revolving fire-works and the whirl-i-gig, used for watering lawns and as an ornament in fountains, are constructed on the same principle.—An ingenious pupil

sides of which are small apertures. It rests in a socket, so as to revolve freely. Water is supplied from a tank above. If the openings in the arms are closed, when the cylinder is filled with water the pressure is equal in all directions and the machine is at rest. If now we open an aperture, the pressure is relieved on that side, and the arm flies back from the unbalanced pressure of the column of water above.

Fig. 89.



5. Waves are produced by the friction of the wind against the surface of the water. The wind raises the particles of water and gravity draws them back again. They thus vibrate up and down, but do not advance.* The forward movement of the wave is an illusion. The *form* of the wave progresses, but not the water of which it is composed, any more than the thread of the screw which we turn in our hand, or the undulations of a rope or carpet which is shaken, or the stalks of grain which bend in billows as the wind sweeps over them.

The corresponding parts of different waves are said to be *like phases.* The distance between two like phases, or between the crests

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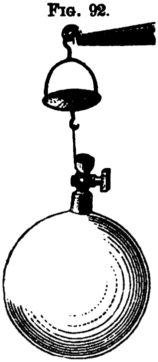
can easily construct a Reaction-wheel of straws or quills, pouring the water into the upright tube by means of a pitcher or admitting it slowly through a siphon from a pail of water placed on a table above.

* Near the shore the oscillations are shorter, and the waves unbalanced by the deep water, are forced forward till the lower part of each one is checked by the friction on the sandy beach, the front becomes well-nigh vertical, and the upper part curls over and falls beyond. The size of "mountain billows" has been exaggerated. Along the coast they may reach 90 feet, but in the open sea the highest wave, from the deepest "trough" to the very topmost "crest," rarely measures over 30 feet.

valve, P, in the piston, also opening upward. Suppose the piston is at the bottom and both valves shut. Let it now be raised, and a vacuum will be produced in the cylinder; the expansive force of the atmosphere in the receiver will open the valve E and drive the air through to fill this empty space. When the piston descends, the valve E will close, while the valve P will open, and the air will pass up above the piston. On elevating the piston a second time, this air is removed from the cylinder, while the air from the receiver passes through as before. At each stroke a portion of the atmosphere is drawn off; but the expansive force becomes less and less, until finally it is insufficient to lift the valves. For this reason a perfect vacuum cannot be obtained.

FIG. 92.



2. The Condenser, in construction, is the reverse of the air-pump. It is used to force into a vessel an increased quantity of air.*

3. Properties of Air.—(1.) WEIGHT.—Exhaust the air from a flask which holds 100 cubic inches, and then balance it. On turning the stop-cock, the air will rush in with a whizzing noise and the flask descend. It will require 31 grains to restore the equipoise.†

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* The practical applications of this pump are numerous. The soda manufacturer uses it to condense carbonic acid in soda-water reservoirs.—The engineer employs it in laying the foundations of bridges. Large tubes or *caissons* are lowered to the bed of the stream, and air being forced in, drives out the water. The workmen are let into the caissons by a sort of trap, and work in this condensed atmosphere with increased ease.—Pneumatic despatch-tubes contain a kind of train holding the mail, and back of this a piston fitting the tube. Air is forced in behind the piston or exhausted before it, and so the train is driven through the tube at a high speed.—In the Westinghouse air-brake, condensed air is forced along a tube running underneath the cars, and by its elastic force drives the brakes against the wheel.

† Hermetically close one end of a piece of iron gas-pipe, and fit a stop-cock to the other. With a condenser crowd into the tube several atmospheres. Weigh the tube in a grocer's balance. Turn the stop-cock and let the air escape. Then the beam will rise. The amount of the weights required to be added to restore the equilibrium will show the weight of the condensed air.

(2.) Elasticity is shown in a pop-gun. We compress the atmosphere in the barrel until the elastic force drives out the stopper with a loud report. As we crowd down the piston we feel the elasticity of the air yielding to our strength, like a bent spring.—The bottle-imps, or Cartesian divers, illustrate the same property. Fig. 93 represents a simple form of this apparatus. The cover of a fruit-jar is fitted with a tin tube, which is inserted in a syringe-bulb. The jar is filled with water and the diver placed within. This is a hollow image of glass, having a small opening at the end of the curved tail. If we squeeze the bulb, the air will be forced into the jar and the water will transmit the pressure to the air in the image. This being compressed, more water will enter, and the diver will descend. On relaxing the grasp of the hand on the bulb, the air will return into it, the air in the image will expand, by its elastic force driving out the water, and the diver, thus lightened of his ballast, will ascend. The nearer the image is to the bottom, the less force will be required to move it. With a little care it can be made to respond to the slightest pressure, and will rise and fall as if instinct with life.*

Fig. 93.

Fig. 94.

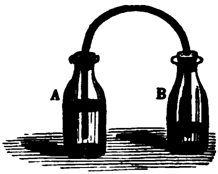
(3.) Expansibility.—Let a well-dried bladder be partly filled with air and tightly closed. Place it under the receiver and exhaust the air. The air in the bladder expanding will burst it into shreds.

Take two bottles partly filled with

* This experiment shows also the buoyant force of liquids, their transmission of pressure in every direction, the increase of the pressure in proportion to the depth, and the principle of Barker's Mill. (See note, p. 118.)

colored water. Let a bent tube be inserted tightly in A and loosely in B. Place this apparatus under the receiver and exhaust the air. The expansive force of the air in A will drive the water over into B. On re-admitting the air into the receiver, the pressure will return the water into A. It may thus be driven from bottle to bottle at pleasure.*

Fig. 95.



Hero's fountain acts on the same principle, as may be seen by an examination of Fig. 96. Having removed the jet-tube, the upper globe is partly filled with water. The tube being then replaced, water is poured into the basin on top. The liquid runs down the pipe at the right, into the lower globe. The air in that globe is driven up the tube at the left, into the upper globe, and by its elasticity forces the water there out through the jet-tube, forming a tiny fountain.

Fig. 96.

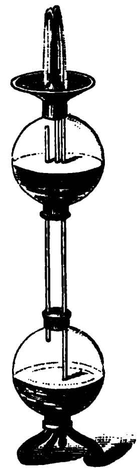


Fig. 97.

4. Pressure of the Air.—(1.) The Proof.—If we cover a hand-glass with one hand, as in Fig. 97, on exhausting the air we shall find the pressure painful.† Tie over one

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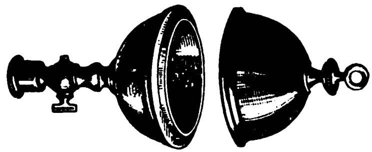
* Prick a hole in the small end of an egg and place the egg with the big end up in a wine-glass. On exhausting the receiver, the bubble of air in the upper part of the egg will drive the contents down into the glass, and on admitting the air they will be forced back again.

† The exhaustion of the air does not *produce* the pressure on the hand; it simply *reveals* it. The average pressure on each person is 16 tons. It is equal, however, on all parts of the body and is counteracted by the air within. Hence we never notice it. Persons who go up high mountains or go down in diving-bells feel the change in the pressure.

end of the glass a piece of wet bladder. When dry, exhaust the air, and the membrane will burst with a sharp report.*

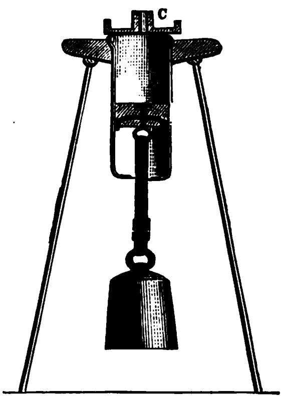
Fig. 98.



The *Magdeburg Hemispheres* are named from the city in which Guericke, their inventor, resided. They consist of two small brass hemispheres, which fit closely together, but may be separated at pleasure. If, however, the air be exhausted from within, several persons will be required to pull them apart.† In whatever position the hemispheres are held, the pressure is the same.

Fig. 99.

Fig. 100.



(2.) Upward Pressure. — Fill a tumbler with water, and then lay a sheet of paper over the top. Quickly invert the glass, and the water will be supported by the upward pressure of the air.—Within the glass cylinder, Fig. 100, is a piston working air-tight. Connect C with the pump by a rubber tube

* To show the crushing force of the atmosphere, take a tin cylinder 15 inches long and 4 inches in diameter. Fit one end with a stop-cock or merely leave a hole for the exit of the steam. Put in a little water and boil. When the air is entirely driven out, turn the stop-cock or close the opening with a bit of solder. Pour cold water over the outside to condense the steam, when the cylinder will collapse as if struck by a heavy blow.

† In the Museum at Berlin the hemispheres used by Guericke in his experiments are preserved. They are of copper, and, by the author's measurements, 22 inches interior diameter with a flange an inch wide, making the entire diameter 2 feet. Accompanying is a Latin book by the burgomaster describing numerous pneumatic experiments which he had performed, and containing a wood-cut representing three spans of horses on each side trying to separate the hemispheres.

and exhaust the air. The weight will leap up as if caught by a spring.

(3.) BUOYANT FORCE OF THE AIR.—The law of Archimedes (p. 93) holds true in gases. Smoke and other light substances float in the air, as wood does in water, because they are lighter and are buoyed with a force equal to the weight of the air they displace. A hollow sphere of copper, Fig. 101, is balanced in the air by a solid lead weight, but it instantly falls on being placed under the receiver and the

FIG. 101.

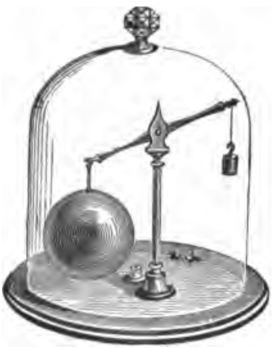


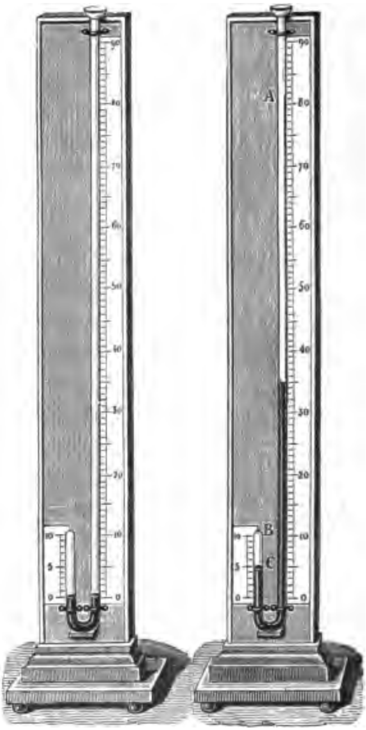
FIG. 102.

air exhausted. This shows that its weight was partly sustained by the buoyant force of the air.

(4.) THE PRESSURE OF THE AIR SUSTAINS A COLUMN OF MERCURY 30 INCHES HIGH, OF WATER 34 FEET HIGH, AND IS 15 LBS. PER SQUARE INCH. Take a strong glass tube about three feet in length, and tie over one end a piece of wet bladder. When dry, fill the tube with mercury, and invert it in a cup of the same liquid. The mercury will sink to a height of about 30 inches. If the area of the tube be one inch, the metal will weigh about 15 lbs. The weight of the column of mercury is equal to the downward pressure on

each square inch of the surface of the mercury in the cup. Hence we conclude that the pressure of the atmosphere is 15 lbs. per square inch, and will balance a column of mercury 30 inches high. As water is $13\frac{1}{2}$ times lighter than mercury, the same pressure would balance a column of that liquid $13\frac{1}{2}$ times higher, or $33\frac{3}{4}$ feet.*

Fig. 103. Fig. 104.



(5.) Pressure of the air varies.† Changes of temperature, moisture, etc., constantly vary the weight of the air, and change the height of the column of liquid it can support. The pressure of the air also increases with the depth. Hence, in a valley its weight is greater than on a mountain. The figures given in the last paragraph apply only to the level of the sea and a temperature of 60° F. They are the standards for reference.

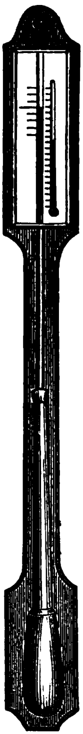
(6.) Mariotte's Law.—Fig. 103 represents a long, bent ‡

* Pour on the mercury in the cup (Fig. 102) a little water colored with red ink. Then raise the end of the tube above the surface of the metal, but not above that of the water which will rise in the tube, the mercury passing down in beautifully-beaded globules. The mercurial column is only 30 inches high, while the water will fill the tube. Finish the experiment by puncturing the bladder with a pin, when the water will instantly fall to the cup below.

† We live at the bottom of an aërial ocean whose depth is many times that of the deepest sea. Its invisible tides surge round us on every side. More restless than the sea, its waves beat to and fro, and never know a calm.

‡ By cautiously inclining the apparatus, when a little air will escape, and adding more mercury if needed, the liquid can be made to stand at zero in both arms.

FIG. 105.



glass tube with the end of the short arm closed. Pour mercury into the long arm until it rises to the point marked zero. It stands at the same height in both arms, and there is an equilibrium. The air presses on the mercury in the long arm with a force equal to a column of mercury 30 inches high, and the elastic force of the air confined in the short arm is equal to the same amount. Now pour additional mercury into the long arm until it stands at 30 inches above that in the short arm (Fig. 104), and the pressure is doubled. In the short arm, the air is condensed to one-half its former dimensions, and the expansive force is also doubled.* We therefore conclude that *the elasticity of a gas increases, and the volume diminishes in proportion to the pressure upon it.*

(7.) The BAROMETER is an instrument for measuring the pressure of the air. It consists essentially of the tube and cup of mercury in Fig. 102. A scale is attached for convenience of reference. The barometer is used (*a*) to indicate the weather, and (*b*) to measure the height of mountains.

It does not directly foretell the weather. It simply shows the varying weight of the air, from which we must draw our conclusions. A continued rise of the mercury indicates fair weather, and a continued fall, foul weather.† Since the pressure diminishes above the level of the sea, the observer ascertains the fall of

* The force with which the flying molecules of air (note, p. 50) beat against the walls of any confining vessel will increase with the diminution of the space through which they can pass. If we give them only half the distance to fly through, they will strike twice as often and exert twice the pressure.

† Mercury is used for filling the barometer because of its weight and low freezing-point. It is said that the first barometer was filled with water. The inventor, Otto von Guericke, erected a tall tube reaching from a cistern in the cellar up through the roof of his house. A wooden image was placed within the tube, floating upon the water. On fine days, this novel weather-prophet would rise above the roof-top and peep out upon the queer old gables of that ancient city, while in foul weather he

the mercury in the barometer, and the temperature by the thermometer; and then, by reference to tables, determines the height.

5. Pumps.—(1.) The LIFTING-PUMP contains two valves opening upward—one, *a*, at the top of the *suction-pipe*, B; the other, *c*, in the piston. Suppose the handle to be raised,

FIG. 106.

FIG. 107.

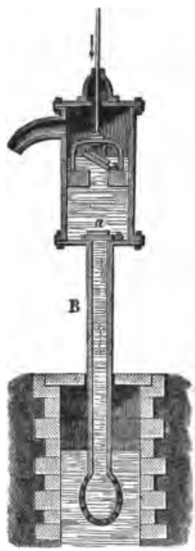
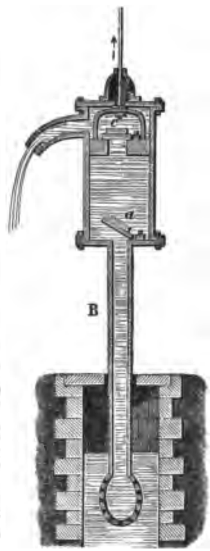


FIG. 108.



the piston at the bottom of the cylinder and both valves closed. Now depress the pump-handle and elevate the piston. This will produce a partial vacuum in the suction-pipe. The pressure of the air on the surface of the water below will force the water up the pipe, open the valve, and

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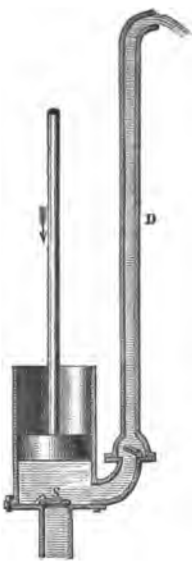
would retire to the protection of the garret. The accuracy of these movements attracted the attention of the neighbors. Finally, becoming suspicious of Otto's piety, they accused him of being in league with the devil. So the offending philosopher relieved this wicked wooden man from longer dancing attendance upon the weather, and the staid old city was once more at peace.

partly fill the chamber. Let the pump-handle be elevated again, and the piston depressed. The valve *a* will then close, the valve *c* will open and the water will rise above the piston (Fig. 107). When the pump-handle is lowered the second time and the piston elevated, the water is lifted up to the spout, whence it flows out; while at the same time the lower valve opens and the water is forced up from below by the pressure of the air (Fig. 108).*

(2.) The FORCE-PUMP has no valve in the piston. The water rises above the lower valve as in the lifting-pump. When the piston descends, the pressure opens the valve and forces the water up the pipe D. This pipe may be made of any length, and thus the water driven to any height.

FIG. 109.



(3.) The FIRE-ENGINE consists of two force-pumps with an air-chamber. The water is driven by the pistons *m*, *n*, alternately, into the chamber R, whence the air, by its expansive force, throws it out in a continuous stream through the hose-pipe attached at Z (Fig. 110).

6. The Siphon is a U-shaped tube, having one arm longer than the other. Insert the short arm in the water, and then applying the mouth to the long arm, exhaust the air. The water will flow from the long arm until the end of the short arm is uncovered.†

* If the valves and piston were fitted air-tight, the water could be raised 34 feet (more exactly 13½ times the height of the barometric column) to the lower valve, but owing to various imperfections it commonly reaches about 28 feet. For a similar reason we sometimes find a dozen strokes necessary to "bring water."

† An instructive experiment may be given if we allow the water to run from one tumbler into another until just before the flow ceases; then quickly elevate the glass containing the long arm, carefully keeping both ends of the siphon under the water, when the flow will set back to the first tumbler. Thus we may alternate until we

FIG. 110.

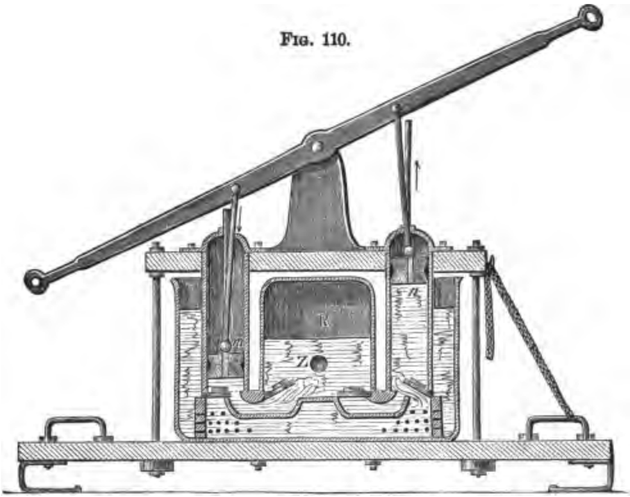
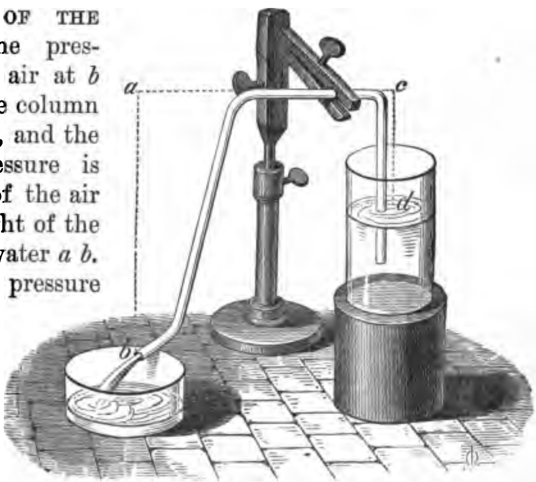


FIG. 111.



THEORY OF THE SIPHON.—The pressure of the air at *b* holds up the column of water *a b*, and the upward pressure is the weight of the air less the weight of the column of water *a b*. The upward pressure at *d* is the weight of the air minus the weight of the column

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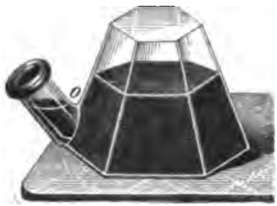
see that the water flows to the lower level, and ceases whenever it reaches the same level in both glasses. It will add to the beauty of this as well as of many other experiments, to color the water with a few scales of magenta, or with red ink.

of water *c d*. Now *c d* is less than *a b*, and the water in the tube is driven toward the longer arm by a force equal to the difference in the weight of the two arms.

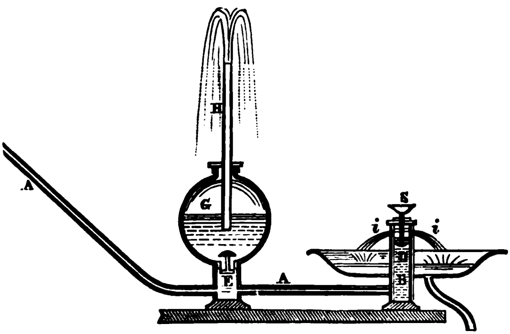
FIG. 112.



7. The Pneumatic Inkstand can be filled only when tipped so that the nozzle is at the top. The pressure of the air will retain the ink when the stand is placed upright. When used below *o*, a bubble of air passes in, forcing the ink into the nozzle.

8. The Hydraulic Ram is a machine for raising water where there is a slight fall. The water enters through the

FIG. 113.



pipe A, fills the reservoir B, and lifts the valve D. As that closes, the shock raises the valve E and drives the water into the air-chamber G. D falls again as soon as an equilibrium is restored. A second shock follows, and more water is thrown into G. When the air in G is sufficiently condensed, its elastic force drives the water through the pipe H.

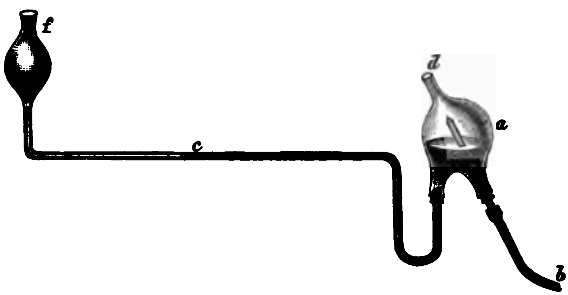
9. The Atomizer is used to turn a liquid into spray.

The blast of air driven from the rubber bulb, as it passes over the end of the upright tube, sweeps along the neighboring molecules of air and produces a partial vacuum in the tube.* The pressure of the air in the bottle drives the liquid up the tube, and at the mouth the blast of air carries it off in fine drops.

FIG. 114.

The action of a current of air in dragging along with it the adjacent still atmosphere and so tending to produce a vacuum, is shown by the apparatus represented in Fig. 115. A globe, *a*, is connected

FIG. 115.



* In locomotives, this principle of the adhesion of gases to gases is applied to produce a draft. The waste steam is thrown into the smoke-pipe, and this current sweeps off the smoke from the fire, while the pressure of the atmosphere outside forces the air through the furnace and increases the combustion.—A familiar illustration may be devised by taking two discs of cardboard, the lower one fitted with a quill, and the upper one merely kept from sliding off by a pin thrust through it and extending into the quill. The more forcibly air is driven through the quill against the upper disc, the more firmly it will be held to its place. See article "Ball Paradox," in *Popular Science Monthly*, April, 1877.—Faraday used to illustrate the principle thus: Hold the hand out flat with the fingers extended and pressed together. Place underneath a piece of paper two inches square. Blow through the opening between the index and the middle finger, and so long as the current is passing the paper will not fall.

with a horizontal tube, *c*, containing colored water. Close the opening *d* with the finger, and with the mouth at *b* draw the air out of the globe. A slight rarefaction will cause the liquid, by the pressure of the air at the opening *f*, to be forced into *a*. Now, if, instead of drawing the air out at *b*, a jet of air be forced through the tube and out at *d*, the same effect will be produced.

10. Height of the Air.—Three opposing forces act upon the air, viz.: gravity, which binds it to the earth, and the centrifugal and repellent forces, which tend to hurl it into space. There must be a point where these balance. At the height of 3.4 miles the mercury in the barometer stands at 15 inches, indicating that half the atmosphere is within about 3½ miles of the earth's surface. The height of the atmosphere is variously stated at from 50 to 500 miles.

PRACTICAL QUESTIONS.—1. Why must we make two openings in a barrel of cider when we tap it? 2. What is the weight of 10 cubic feet of air? 3. What is the pressure of the air on 1 square rod of land? 4. What is the pressure on a pair of Magdeburg hemispheres 4 inches in diameter? 5. How high a column of water can the air sustain when the barometric column stands at 28 inches? 6. If we should add a pressure of two atmospheres (30 lbs. to the square inch), what would be the volume of 100 cubic inches of common air? 7. If, while the water is running through the siphon, we quickly lift the long arm, what is the effect on the water in the siphon? If we lift the entire siphon? 8. When the mercury stands at 29½ inches in the barometer, how high above the surface of the water can we place the lower pump-valve? 9. Can we raise water to a higher level by means of a siphon? 10. If the air in the chamber of a fire-engine be condensed to $\frac{1}{10}$ its former bulk, what will be the pressure due to the expansive force of the air on every square inch of the air-chamber? 11. What causes the bubbles to rise to the surface when we put a lump of loaf-sugar in hot tea? 12. To what height can a balloon ascend? What weight can it lift? 13. The rise and fall of the barometric column shows that the air is lighter in foul and heavier in fair weather. Why is this? *Ans.* Vapor of water is only half as heavy as dry air. When there is a large quantity present in the atmosphere, displacing its own bulk of air, the weight of the atmosphere will be correspondingly diminished. 14. When smoke ascends in a straight line from chimneys, is it a proof of the rarity or the density of the air? 15. Explain the action of the common leather-sucker. 16. Did you ever see a bottle really empty? 17. Why is it so tiresome to walk in miry clay? *Ans.* Because the upward pressure of the air is removed from our feet. 18. How does the variation in the pressure of the air affect those who ascend lofty mountains? Who descend in diving-bells? 19. Explain the theory of "sucking cider" through a straw. 20. Would it make any difference in the action of the siphon if the limbs were of unequal diameter? 21. If the receiver of an air-pump is 5 times as large as the barrel, how many strokes of the piston will be needed to diminish the air nearly one-half? 22. What would be the effect of making a small hole in the top of a diving-bell while in use? 23. The pressure of the atmosphere being 1.03 kg. per sq. cm., what is the amount on 1 are? On 10 metres?

SUMMARY.

Hydrostatics treats of the laws of equilibrium in liquids. Pressure is transmitted by liquids equally in every direction. Water thus becomes a "mechanical power," as in the "Hydraulic Press." Liquids acted on by their weight only, at the same depth, press downward, upward, and sidewise with equal force. This pressure is independent of the size of the vessel, but increases with the depth. Wells, springs, aqueducts, fountains and the water-supply of cities illustrate the tendency of water to seek its level. The ancients understood this law, but had no suitable material for making the immense pipes needed; just so the art of printing waited the invention of paper. Specific gravity, or the relative weights of the same bulk of different substances, is found by comparing them with the weight of the same bulk of water. This is easily done, since, according to the law of Archimedes, a body immersed in water is buoyed up by a force equal to the weight of the water displaced; *i. e.*, it loses in weight an amount equal to that of the same bulk of water. Hence spec. grav. $= \frac{\text{weight in air}}{\text{weight in air} - \text{weight in water}}$. A floating body displaces only its weight of liquid. This explains the buoyancy of a ship, why a floating log is partly out of water, and many similar phenomena.

Hydraulics treats of moving liquids. The laws of falling bodies in the main apply. So that a descending jet of water will acquire the same velocity that a stone would in falling to the ground from the surface of the water; and an ascending jet would need to have the same velocity in order to reach that height. The quantity of water discharged through any orifice equals the area of the opening multiplied by the velocity of the stream. The chief resistance to the motion of a liquid is the friction of the air and against the sides of the pipe, and, in the case of rivers, against the banks and bottom of the channel. The force of falling water is utilized in the arts by means of water wheels. There are four kinds—overshot, undershot, breast, and turbine. The principles of wave motion, so essential to the understanding of sound, light, etc., are easiest studied in connection with water. A stone let fall into a quiet pool sets in motion a series of concentric waves, whose particles merely rise and fall, while the movement passes to the outermost edge of the water, and is then transmitted to the ground beyond. The velocity of the particles is much less than that of the wave itself. A handful of stones acts in the same way,

but sets in motion many series of waves. Hence arise the phenomena of interference.

Pneumatics treats of the properties and the laws of equilibrium of gases. The air being composed of matter, has all the properties we associate with matter, as weight, indestructibility, extension, compressibility, etc. In addition, it is remarkable for its elasticity.* The elasticity of the air, according to Mariotte's (and Boyle's) law, is inversely proportional to its volume, and that is inversely proportional to the pressure upon the air; both heat and pressure increasing the elasticity of a gas. The air, like other fluids, transmits the weight of its own particles, as well as any outside pressure, equally in every direction; hence the upward pressure or buoyant force of the atmosphere. A balloon rises because it is buoyed up by a force equal to the weight of the air it displaces. It floats in the air for the same reason that a ship floats on the ocean. When smoke falls it is heavier, and when it rises it is lighter than the surrounding atmosphere. The air-pump is used for exhausting the air from, and the condenser for condensing the air into, a receiver. A vacuum in which there remains only $\frac{1}{1000000}$ of the atmosphere can be obtained by means of Sprengel's air-pump, which acts on the principle of the adhesion of the air to a column of falling mercury. The average weight of the air being 15 lbs. to the square inch, equals that of a column of water 34 feet, and of mercury 30 inches or 760 millimetres high. This amount varies incessantly through atmospheric changes caused by alterations in the wind, heat of the sun, etc. The barometer measures the weight of the atmosphere, and is used to determine the height of mountains and the changes of the weather. The action of the siphon, the pneumatic inkstand, and of the different kinds of pumps, is based upon the pressure of the air.

* The elasticity of the air, as well as the principles explained by the Cartesian diver, Fig. 98, may be illustrated in the following simple manner: Fill with water a wide-mouth, 8-oz. bottle, and also a tiny vial, such as is used by homœopathists. Invert the vial and a few drops of water will run out. Now put it inverted into the bottle, and if it does not sink just below the surface and there float, take it out and add or remove a little water, as may be needed. When this result is reached, cork the bottle so that the cork touches the water. Any pressure on the cork will then be transmitted to the air in the vial, as in the image in Fig. 98.

HISTORICAL SKETCH.

Hydrostatics is comparatively a modern science. The Romans had a knowledge of the fact that "liquids rise to the level of their source," but they had no means of making iron pipes strong enough to resist the pressure.* They were therefore forced to carry water into the imperial city by means of enormous aqueducts, one of which was 63 miles long, and was supported by arches 100 feet high. The ancient Egyptians and Chaldeans were probably the first to investigate the most obvious laws of liquids from the necessity of irrigating their land. Archimedes, in the 3d century B. C., invented a kind of pump called *Archimedes' Screw*, demonstrated the principle of equilibrium, known now as "*Archimedes' Law*" (p. 117), and found out the method of obtaining the specific gravity of bodies. The discovery of the last is historical. Hiero of Syracuse suspected that a gold crown had been fraudulently alloyed with silver. He accordingly asked Archimedes to find out the fact without injuring the workmanship of the crown. One day going into a bath-tub full of water, the thought struck the philosopher that as much water must run over the side as was equal to the bulk of his body. Electrified by the idea, he sprang out and ran through the streets, shouting: "Eurêka!" (I have found it!)

The ancients never dreamed of associating the air with gross matter. To them it was the spirit, the life, the breath. Noticing how the atmosphere rushes in to fill any vacant space, the followers of Aristotle explained it by saying, "Nature abhors a vacuum." This principle answered the purpose of philosophers for 2,000 years. In 1640, some workmen were employed by the Duke of Tuscany to dig a deep well near Florence. They found to their surprise that the water would not rise in the pump as high as the lower valve. More disgusted with nature than nature was with the vacuum in their pump, they applied to Galileo. The aged philosopher answered—half in jest, we hope, certainly he was half in earnest—"Nature does not abhor a vacuum beyond 34 feet." His pupil, Torricelli, how-

* The ancient engineers sometimes availed themselves of this principle. Not far from Rachel's Tomb, Jerusalem, are the remains of a conduit once used for supplying the city with water. The valley was crossed by means of an inverted siphon. The pipe was about two miles long and fifteen inches in diameter. It consisted of perforated blocks of stone, ground smooth at the joints, and fastened with a hard cement.

ever, discovered the secret. He reasoned that there is a force which holds up the water, and as mercury is 13½ times as heavy as water, it would sustain a column of that liquid only 33 feet ÷ 13½ = 30 inches high. Trying the experiment shown in Fig. 102, he verified the conclusion that the weight of the air is the unknown force. But the opinion was not generally received. Pascal next reasoned that if the weight of the air is really the force, then at the summit of a high mountain it is weakened, and the column would be lower. He accordingly carried his apparatus to the top of a steeple, and finding a slight fall in the mercury, he asked his brother-in-law, who lived near Puy de Dôme, a mountain in Southern France, to test the conclusion. On trial, it was found that the mercury fell 3 inches. "A result," wrote Perrier, "which ravished us with admiration and astonishment." Thus was discovered the germ of our modern barometer, and the dogma of the philosophers soon gave place to the law of gravitation and our present views concerning the atmosphere.

Consult Pepper's "Cyclopædic Science"; Bert's "Atmospheric Pressure and Life," in Popular Science Monthly, Vol. XI, p. 316; "Appleton's Cyclopædia," Articles on Hydromechanics, Atmosphere, Pneumatics, etc. Delaunay, "Mécanique Rationnelle"; Boutan et D'Almeida, "Cours de Physique"; Müller, "Lehrbuch der Physik und Meteorologie"; Müller, "Lehrbuch der Kosmischen Physik"; Wüllner, "Lehrbuch der Experimental-Physik"; Mousson, "Die Physik auf Grundlage der Erfahrung"; Beetz, "Leitfaden der Physik"; Kuelp, "Die Schule des Physikers."

On the theory of Wave-Motion, and the subjects of Sound and Light, which are now to follow, consult Lockyer's "Studies in Spectrum Analysis"; Lloyd's "Wave Theory"; Taylor's "Sound and Harmony"; Blaserna's "Theory of Sound in Relation to Music"; Tyndall's "Sound" and "Light"; Lockyer's "Water-waves and Sound-waves" in Popular Science Monthly, Vol. XIII, p. 166; Shaw's "How Sound and Words are Produced," in Popular Science Monthly, Vol. XIII, p. 43; Schellen's "Spectrum Analysis"; Airy's Optics; Lockyer's Spectroscope; Chevreul's Colors; Spottiswoode's "Polarization of Light"; Lommel's "Nature of Light"; Helmholtz's "Popular Lectures on Scientific Subjects"; "Appleton's Cyclopædia," Articles on Sound, Light, Spectrum, Spectrum Analysis, Spectacles, Heat, etc.; Stokes's "Absorption and Colors," and Forbes's "Radiation," in Science Lectures at South Kensington, Vol. I; Mayer and Barnard's Light; Draper's "Popular Exposition of some Scientific Experiments," in Harper's Magazine for 1877; Core's "Modern Discoveries in Sound," in Manchester Science Lectures, '77–8; Dolbeare's "Art of Projecting"; Draper's "Scientific Memoirs"; Steele's Physiology. Section on Sight, pp. 187–196.

VI.

ON SOUND.

"*Science ought to teach us to see the invisible as well as the visible in nature: to picture to our mind's eye those operations that entirely elude the eye of the body; to look at the very atoms of matter, in motion and in rest, and to follow them forth into the world of the senses.*"—TYNDALL.

ANALYSIS.

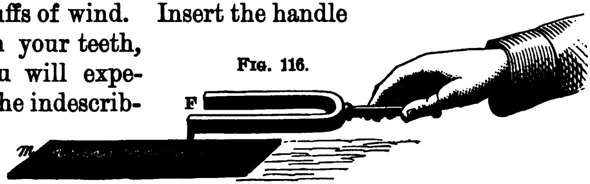
SOUND.

1. PRODUCTION OF SOUND.
2. TRANSMISSION OF SOUND.
   - (1.) Through air.
   - (2.) In a vacuum.
   - (3.) Velocity.
     - (a.) *Depends on what?*
     - (b.) *Rate in air.*
     - (c.) *Rate in water.*
     - (d.) *Rate in solids.*
     - (e.) *Velocity is uniform.*
     - (f.) *Used to find distance.*
   - (4.) Intensity.
     - (a.) *Depends on what?*
     - (b.) *Law of.*
     - (c.) *Speaking-tubes, etc.*
3. REFRACTION OF SOUND.
4. REFLECTION OF SOUND.
   - (1.) Law of.
   - (2.) Echoes.
   - (3.) Decrease of Intensity.
   - (4.) Acoustic Clouds.
5. MUSICAL SOUNDS.
   - (1.) Difference between Noise and Music.
   - (2.) Pitch.
   - (3.) To find Number of Waves.
   - (4.) To find Length of Waves.
   - (5.) Unison.
6. SUPER-POSITION OF SOUND-WAVES.
7. VIBRATION OF CORDS.
   - — Definitions.
   - (1.) Sonometer.
   - (2.) Three Laws.
   - (3.) Nodes.
   - (4.) Acoustic Figures.
   - (5.) Harmonics.
   - (6.) Nodes of Bell.
   - (7.) Nodes of Sounding-Board.
   - (8.) Musical Scale.
8. WIND INSTRUMENTS.
9. SYMPATHETIC VIBRATIONS.
   - — Illustrations.
   - (1.) Sensitive Flames.
   - (2.) Singing Flames.
10. THE PHONOGRAPH.
11. THE EAR.
    - — Description.
    - (1.) Range of.
    - (2.) Ability to Detect Sound.

ACOUSTICS, OR THE SCIENCE OF SOUND.*

1. Production of Sound.—By lightly tapping a glass fruit-dish, we can throw the sides into motion visible to the eye.—Fill a goblet half-full of water, and rub a wet finger lightly around the upper edge of the glass. The sides will vibrate, and cause tiny waves to ripple the surface of the water.—Hold a card close to the prongs of a vibrating tuning-fork, and you can hear the repeated taps. Place the cheek near them, and you will feel the little puffs of wind. Insert the handle between your teeth, and you will experience the indescribable thrill of the swinging metal. The tuning-fork may be made to draw the outline of its vibrations upon a smoked-glass. Fasten upon one prong a sharp point, and drawing the fork along, a sinuous line will show the width (amplitude) of the vibrations.

FIG. 116.



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* The term *sound* is used in two senses—the *subjective* (which has reference to our mind) and the *objective* (which refers to the objects around us). (1.) Sound is the sensation produced upon the organ of hearing by vibrations in matter. In this use of the word there can be no sound where there is no ear to catch the vibrations.—An oak falls in the forest, and if there is no ear to hear it there is no noise, and the old tree drops quietly to its resting-place.—Niagara's flood poured over its rocky precipice for ages, but fell silently to the ground. There were the vibrations of earth and air, but there was no ear to receive them and translate them into sound. When the first foot trod the primeval solitude, and the ear felt the pulsations from the torrent, then the roaring cataract found a voice and broke its lasting silence.—A trumpet does not sound. It only carves the air into waves. The tympanum is the beach on which these break into sound. (2.) Sound is those vibrations of matter capable of producing a sensation upon the organ of hearing. In this use of the word there can be a sound in the absence of the ear. An object falls and the vibrations are produced, though there may be no organ of hearing to receive an impression from them. This is the sense in which the term sound is commonly used.

2. Transmission of Sound.—(1.) THROUGH AIR. The prong of a tuning-fork advances condensing the air in front, and then recedes, leaving behind it a partial vacuum. This process is repeated until the fork comes to rest, and the sound ceases. Each vibration produces a *sound-wave* of air, which contains one condensation and one rarefaction. In water, we measure a wave-length from crest to crest; in air, from condensation to condensation. The condensation of the sound-wave corresponds to the crest, and the rarefaction of the sound-wave to the hollow of the water-wave. In

FIG. 117.

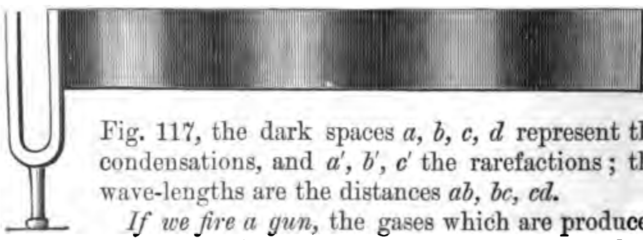
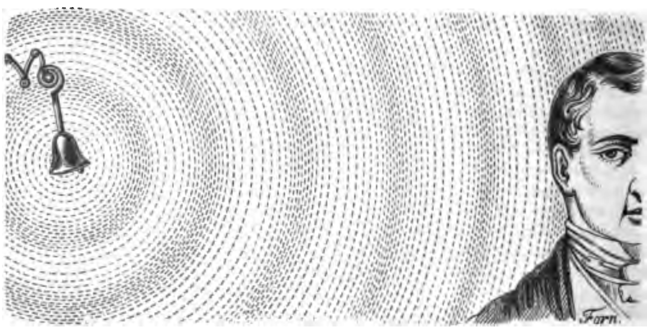


Fig. 117, the dark spaces *a, b, c, d* represent the condensations, and *a', b', c'* the rarefactions; the wave-lengths are the distances *ab, bc, cd.*

If we fire a gun, the gases which are produced expand suddenly and force the air outward in every direction. This hollow shell of condensed air imparts its motion to that next, while it springs back by its elasticity

FIG. 118.

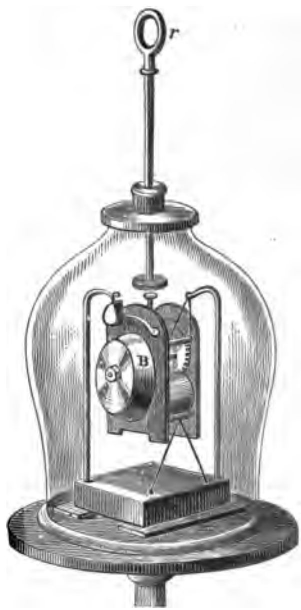


and becomes rarefied. The second shell rushes forward with

the motion received, then bounds back and becomes rarefied. Thus each shell of air takes up the motion and imparts it to the next. The wave, consisting of a condensation and a rarefaction, proceeds onward. It is, however, as in water-waves, a movement of the *form* only, while the particles vibrate but a short distance to and fro. The molecules in water-waves oscillate *vertically;* those in sound-waves *horizontally,* or parallel to the line of motion.

If a bell be rung, the adjacent air is set in motion; thence, by a series of condensations and rarefactions, the vibrations are conveyed to the ear.

FIG. 119.



When we speak, we do not shoot the air we expel from our lungs into the ear of the listener. We simply condense the air before the mouth and throw it into vibration. Thus a sound-wave is formed.* This spreads in every direction in the form of a sphere of which we are the centre.†

(2.) IN A VACUUM. The bell B (Fig. 119) may be set in motion by the sliding-rod *r*. The apparatus is suspended by silk cords, that no vibration may be conducted through the pump. If the air be exhausted, the sound

* A continuous blast of air produces no sound. The rush of the grand aërial rivers above us we never hear. They flow on in the upper regions ceaselessly but silently. A whirlwind is noiseless. Let, however, the great billows strike a tree and wrench it from the ground, and we can hear the secondary, shorter waves which set out from the struggling limbs and the tossing leaves.

† "It is marvellous," says Youmans, "how slight an impulse throws a vast amount of air into motion. We can easily hear the song of a bird 500 feet above us. For its melody to reach us it must have filled with wave-pulsations a sphere of air 1,000 feet in diameter, or set in motion 18 tons of the atmosphere."

will become so faint that it cannot be heard, even when the ear is placed close to the receiver.*

In elevated regions sounds are diminished in loudness and sharpness, and it is difficult to carry on a conversation, as the voice must be raised so high. The reverse takes place in deep mines and diving-bells. The sounds then become startlingly distinct, and the workmen are compelled to talk in whispers.

(3.) THE VELOCITY OF SOUND depends on the ratio of the *elasticity* to the *density* of the medium through which it passes. The higher the elasticity, the more promptly and rapidly the motion is transmitted, since the elastic force acts like a bent spring between the molecules; and the greater the density, the more molecules to be set in motion, and hence the slower the transmission.

Sound travels through air (at 32° F.) 1,090 feet per second. A rise in temperature diminishes the density of the air, and thus increases the velocity of sound. A difference of 1° F. makes a variation of about 1 foot. Sound also moves faster in damp than in dry air.

Sound travels through water about 4,700 feet per second. Water being denser than air should convey sound more slowly; but its high elasticity (p. 20) quadruples the rate.

Sound travels through solids faster than through air. This may be illustrated by placing the ear close to the horizontal bar at one end of an iron fence, while a person strikes the other end a sharp blow. Two sounds will reach the ear—one through the metal, and afterward another through the air. The velocity varies with the nature of the solid.† In the metals it is from 4 to 16 times that in air.

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* There would be perfect silence in a perfect vacuum. No sound is transmitted to the earth from the regions of space. The movements of the heavenly bodies are noiseless. In the expressive language of David, "Their voice is not heard."

† Wheatstone invented a beautiful experiment to show the transmission of sound through wood. Upon the top of a music-box, he rested the end of a wooden rod reaching to the room above, and insulated from the ceiling by india rubber. A violin being placed on the top of the rod, the sounds from the box below filled the upper

*Different sounds travel with the same velocity.** A band may be playing at a distance, yet the harmony of the different instruments is preserved. The soft and the loud, the high and the low notes reach the ear at the same time.

Velocity of sound used to find distance. Light travels instantaneously so far as all distances on the earth are concerned. Sound moves more slowly. We see a chopper strike with his axe, and a moment elapses before we hear the blow. If one second intervenes the distance is about 1,090 feet. By means of the second hand of a watch or the beating of our pulse, we can count the seconds that elapse between a flash of lightning and the peal of thunder which follows. Multiplying the velocity of sound by the number of seconds, we obtain the distance of the thunderbolt.

(4.) THE INTENSITY OF SOUND is proportional to the square of the amplitude, *i. e.*, the arc through which the molecules swing to and fro. As in a pendulum, the greater the amplitude the greater the velocity. The force of a striking body depends upon its weight and the square of its velocity (p. 36). So one sound is louder than another, because the air molecules hit the ear-drum with greater force. On the top of a mountain, because of the rare atmosphere, there are fewer molecules to strike the ear; hence, the blow is less intense.

The intensity of sound diminishes as the square of the distance increases.† The sound-wave expands in the form

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room, appearing to emanate from the violin.—Take two small, round, tin boxes and pass a strong string of any length through a hole in the bottom of each, fastening it by a knot. If the string be drawn tightly, and one box be held to the mouth of the speaker and the other to the ear of the listener, the faintest whisper can be heard.

* It has been said that the "heaviest thunder travels no faster than the softest whisper." Mallet, however, found that in blasting with a charge of 2,000 lbs., the velocity was 967 feet per second, while with 12,000 lbs. it was increased to 1,210 feet. Parry in his Arctic travels states that, on a certain occasion, the sound of the sunset-gun reached his ears before the officer's word of command to fire, proving that the report of the cannon travelled sensibly faster than the sound of the voice.

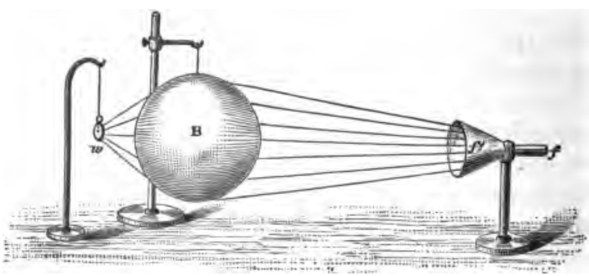
† The same proportion obtains in Gravitation, Sound, Light, and Heat. We have seen how the Pendulum is based upon the force of Gravity, and reveals the Laws of Falling Bodies. Now we find that the Pendulum, and even the principles of Reflected

of a sphere. The larger the sphere, the greater the number of air particles to be set in motion, and the feebler their vibration. The surfaces of spheres are proportional to the squares of their radii; the radii of sound-spheres are their distances from the centre of disturbance. Hence the force with which the molecules will strike the ear decreases as the square of our distance from the sounding body.

Speaking-tubes conduct sound to distant rooms because they prevent the waves from expanding and losing their intensity.* The *ear-trumpet* collects waves of sound and reflects them into the ear. The *speaking-trumpet* is based on the same principle as the speaking-tube. Probably also the sound of the voice is strengthened by the vibrations of the air in the tube.

3. Refraction of Sound.—When a sound-wave goes obliquely from one medium to another, it is bent out of its course. Like light, it may be passed through a lens and

FIG. 120.



brought to a focus. B is a rubber globe, filled with carbonic-acid gas; *w* is a watch, and *f'* a funnel which assists in collecting the wave at *f*, where the ear is placed. The ticks

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Motion and Momentum, are linked with the phenomena of Sound. As we progress further, we shall find how Nature is thus interwoven everywhere with proofs of a common plan and a common Author.

* Biot held a conversation through a Paris water-pipe 3,120 feet long. He says that "it was so easy to be heard, that the only way not to be heard was not to speak at all."

of the watch can be heard, while outside the focus they are inaudible.

4. Reflection of Sound.—When a sound-wave strikes against the surface of another medium, a portion goes on while the rest is reflected.

(1.) THE LAW is that of Motion;—the angle of incidence is equal to that of reflection.* If the reflecting surface be very near, the reflected sound will join the direct one and strengthen it. This accounts for the well-known fact that a speaker can be heard more easily in a room than in the open air, and that a smooth wall back of the stand re-inforces the voice. The old-fashioned "sounding-boards" were by no means inefficient, however singular may have been their appearance. Shells, by their peculiar convolutions, reflect the various sounds which fill even the stillest air. As we hold them to our ear, they are poetically said to "repeat the murmurs of their ocean home."

(2.) ECHOES are produced where the reflecting surface is so distant that we can distinguish the reflected from the direct sound. If the sound be short and quick, this requires at least 56 feet; but if it be an articulate one, 112 feet are necessary. One can pronounce or hear distinctly about five syllables in a second; 1,120 ft. (the velocity at a medium temperature) $\div 5 = 224$ ft.† If the wave travel 224 feet

* Domes and curved walls reflect sound as mirrors do light. Thus, in the gallery under the dome of St. Paul's Cathedral, London, persons standing close to the wall can whisper to each other and be heard at a great distance.—Two persons, placed with their backs to each other, at the foci of an oval room, or "Whispering Gallery," can carry on a conversation that will be inaudible to spectators standing between them.—The covered recesses on the opposite sides of a street, or the arches of a stone bridge, oftentimes reflect sound so as to enable persons seated at the foci to converse in whispers while loud noises are being made in the open space between these semi-domes.

† When several parallel surfaces are properly situated, the echo may be repeated backward and forward in a surprising manner. In Princeton, Ind., there is an echo between two buildings that will return the word "Knickerbocker" twenty times. So many persons visited the place that the city council forbade the use of the echo after 9 o'clock at night.—At Woodstock, England, an echo returns 17 syllables by day and 20 by night. The reflecting surface is distant about 2,300 feet, and a sharp *ha!*

in going and returning, the two sounds will not blend, and the ear can detect an interval between them. A person speaking in a loud voice in front of a mirror 112 feet distant, can distinguish the echo of the last syllable he utters; at 224 feet, the last two syllables, etc.

(3.) DECREASE OF SOUND BY REFLECTION.—If we strike the bell represented in Fig. 119, we shall find a marked difference between its sound under the glass receiver and in the open air. Floors are deadened with tan-bark or mortar, since as the sound-wave passes from particle to particle of the unhomogeneous mass, it becomes weakened by partial reflection. The air at night is more homogeneous, and hence sounds are heard further and more clearly than in the day time.

(4.) ACOUSTIC CLOUDS are masses of moist air of varying density, which act upon sounds as common clouds do upon light, wasting it by repeated reflections. They may exist in the clearest weather. To their presence is to be attributed the variation often noticed in the distance at which well-known sounds, as the ringing of church bells, blowing of engine-whistles, etc., are heard at different times.*

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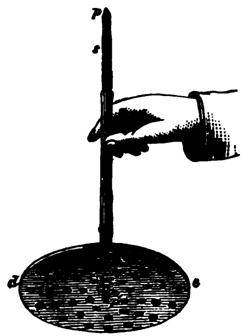
will come back a ringing *ha, ha, ha!*—The echo is often softened, as in the Alpine regions, where it warbles a beautiful accompaniment to the shepherd's horn.—The celebrated echo of the Metelli at Rome was capable of distinctly repeating the first line of the Æneid 8 times.—In Fairfax County, Va., is an echo which will return 20 notes played on a flute, but supplies the place of some notes with their thirds, fifths, or octaves.—The tick of a watch may be heard from one end of the Church of St. Albans to the other.—At Carisbrook Castle, Isle of Wight, is a well 210 feet deep and 12 feet wide, lined with smooth masonry. When a pin is dropped into the well it is distinctly heard to strike the water.—In certain parts of the Colosseum at London the tearing of paper sounds like the patter of hail, while a single exclamation comes back a peal of laughter.—The Dome of the Baptistry of the Cathedral at Pisa (See Frontispiece) has a wonderful echo. During some experiments there, the author found every noise, even the rattle of benches on the pavement below, to be reflected back as if from an immense distance and to return mellowed and softened into music (note, p. 131).

* The extinction of sound by such agencies is often almost incredible. Thus two observers looking across the valley of the Chickahominy at the battle of Gaines's Mill failed to hear a sound of the conflict, though they could clearly see the lines of soldiers, the batteries and the flash of the guns.—These phenomena are ascribed by many (page 264) to an elevation or a depression of the wave-front so that the sound passes above the observer or is stopped before it reaches him. See *Stewart's Physics*, p. 141.

5. Musical Sounds.—(1.) THE DIFFERENCE BETWEEN NOISE AND MUSIC is that between irregular and regular vibrations. Whatever the cause which sets the air in motion, if the vibrations are uniform and rapid enough, the sound is musical. If the ticks of a watch could be made with sufficient rapidity, they would lose their individuality and blend into a musical tone. If the puffs of a locomotive could reach 50 or 60 a second, its approach would be heralded by a tremendous organ-peal.*

FIG. 121.



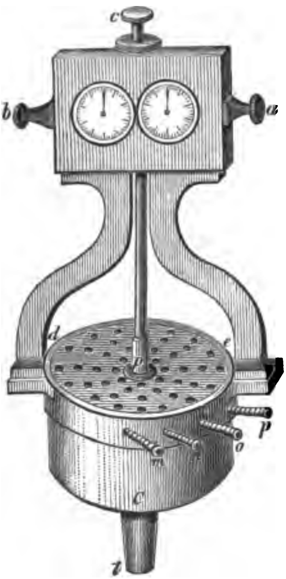
(2.) PITCH depends on the rapidity of the vibrations. Thus if we hold a card against the cogs of the rapidly-revolving wheel in the apparatus shown in Fig. 16, we shall obtain a clear tone; and the faster the wheel turns, the shriller the tone, *i. e.*, the higher the pitch.

(3.) THE NUMBER OF WAVES IN A SOUND is determined by an instrument called the *Siren*. C is a cylindrical box; *t*, a pipe for admitting air; *ab*, a plate pierced with four series of holes, containing 8, 10, 12, and 16 orifices respectively; *m, n, o, p* are stops for closing any series.

* The pavement of London is largely composed of granite blocks, four inches in width. A cab-wheel jolting over this at the rate of eight miles per hour produces a succession of 35 sounds per second. These link themselves into a soft, deep musical tone, that will bear comparison with notes derived from more sentimental sources. This tendency of Nature to music is something wonderful. "Even friction," says Tyndall, "is rhythmic." A bullet flying through the air sings softly as a bird. The limbs and leaves of trees murmur as they sway in the breeze. The rumble of a great city, all the confused noises of Nature when softened by distance, are said to be on one pitch—the key of F. Falling water, singing birds, sighing winds, everywhere attest that the same Divine love of the beautiful which causes the rivers to wind through the landscape, the trees to bend in a graceful curve—the line of beauty—and the rarest flowers to bud and blossom where no eye save His may see them, delights also in the anthem of praise which Nature sings for His ear alone.

The rod *p* is bevelled at *p'* so as to turn in the socket *x*; *de* is a disk with holes corresponding to those in the lower plate, over which it revolves. At *s* is an endless screw, which causes two wheels to rotate, and thus turns the hands upon the dial (Fig. 122). On this we can see the number of revolutions made by the upper disk. The holes in *ab* and *de* are inclined to each other, so that, when a current of air is forced in at *t*, it passes up through the openings in the lower disk, and striking against the sides of those in the upper disk, causes it to revolve. As that turns, it alternately opens and closes the orifices in the lower disk, and thus converts the steady stream of air into uniform puffs. At first they succeed each other so slowly that they may easily be counted. But, as the motion increases, they link themselves together, and burst into a full, melodious note. As the velocity augments, the pitch rises, until the music becomes painfully shrill. Diminish the speed, and the pitch falls.

FIG. 122.



To find, therefore, the number of vibrations in a given sound, force the air through the Siren until the required pitch is reached. See on the dial, at the end of a minute, the number of revolutions of the disk. When the row containing ten holes is open, and the tone C_2, it will indicate 1,536. There were ten puffs of air, or ten waves of sound, in each revolution. $1,536 \times 10 = 15,360$. Dividing this by 60, we have 256, the number per second. When the inner and outer rows of holes are opened, the ear detects the difference of an octave between the two sounds. The one containing 8 produces the lower, and 16 the higher tone.

Hence an *octave* of a tone is caused by double the number of vibrations.

(4.) TO FIND THE LENGTH OF THE WAVE.—Suppose the air in the last experiment was of such a temperature that the foremost sound-wave travelled 1,120 feet in a second. In that space there were 256 sound-waves. Dividing 1,120 by 256, we have 4⅜ feet as the length of each. We thus find the wave-length by dividing the velocity by the number of vibrations per second. As the pitch is elevated by rapidity of vibration, we perceive that the low tones in music are produced by the long waves and the high tones by the short ones.*

(5.) TONES IN UNISON.—If the string of a violin, the cord of a guitar, the parchment of a drum, and the pipe of an organ, produce the same tone, it is because they are executing the same number of vibrations per second. If a voice and a piano perform the same music, the steel strings of the piano and the vocal cords of the singer vibrate together and send out sound-waves of the same length.†

6. Super-position of Sound-waves.—The air may transmit sound-waves from a thousand instruments at once. If the condensation of one wave meet the condensation of another, the sound will be augmented, the condensations becoming more condensed and the rarefactions more rarefied (p. 102). If the condensation of one meet the rarefaction

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* The aerial waves are seemingly shortened when the source of sound is approaching, whether by its own motion or the hearer's, and lengthened when it is receding. In the former case the tone of the sound is more acute, in the latter graver. This is strikingly illustrated when a swift train rushes past a station, the whistle blowing. While the cars are approaching, a person hears a note somewhat sharper; after it has passed, one somewhat flatter than the true note. Still more obvious is the change when two trains pass each other. A person unfamiliar with the arrangement would suppose a different bell was rung. In one case more and in the other fewer waves reach the ears in a second. Just so a ship moving against the sea meets more waves than one moving with it.

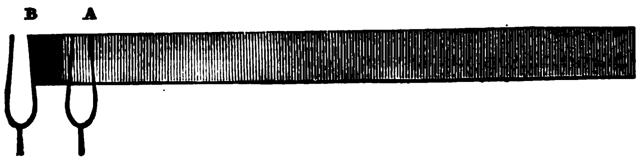
† In order to determine the number and length of the sound-waves produced by a sonorous body, we have only to bring its sound and that of the siren in unison. "The wings of a gnat flap, in flying, at the rate of 15,000 times per second. A tired bee hums on E, while in pursuit of honey it hums contentedly on A. The common horse-fly moves its wings 335 times a second; a honey-bee, 190 times."

of the other, one wave-motion will be striving to push the air molecules forward, and the other to urge them backward. So that, if they meet in exactly opposite phases and the two forces are equal, they will balance each other and silence will ensue.*

FIG. 123.

Suppose we have two tuning-forks, A and B, a wave-length apart, and vibrating in unison. The waves will coincide, as represented by the light and dark shades in Fig. 123. The same result would occur if they were any number of wave-lengths apart. If they are a half wave-length apart, the condensation of A will coincide with the rarefaction of B, and *vice versa*. The effect is represented

FIG. 124.



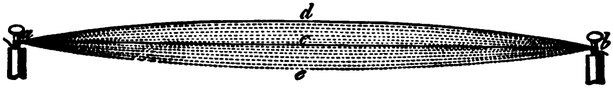
by the uniformity of the shading in Fig. 124. This is termed *interference of sound-waves.*†

7. Vibrations of Cords.—Let *ab* be a stretched cord made to vibrate. The motion from *e* to *d* and back again is termed a *vibration;* that from *e* to *d*, a *half-vibration.*

* Thus a sound added to a sound may produce silence. In the same way, two motions may produce rest; two lights may cause darkness; and two heats may produce cold.

† If we strike a tuning-fork and turn it slowly around before the ear, we shall find four points where the interference of the sound-waves neutralizes the vibrations and causes silence.—Two forks or organ-pipes nearly in unison, produce the well-known "beats," a characteristic phenomenon of interference.

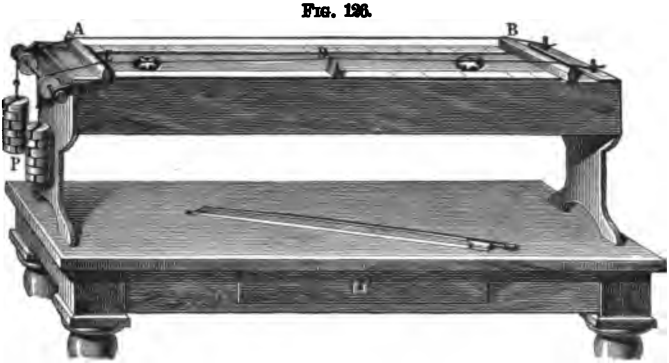
FIG. 125.



The intensity of the sound depends on the width of *ed*, i. e., the amplitude of the vibration.

(1.) THE SONOMETER is an instrument used to investigate the laws which govern the vibrations. It consists of two cords stretched by weights, P, across fixed bridges, AB.

FIG. 126.



The movable bridge, D, serves to lengthen or shorten the cords. Beneath is a wooden box which communicates the vibrations of the cords to the air within. This is the real sounding body.

(2.) THREE LAWS.—I. *The number of vibrations per second increases as the length of the cord decreases.* With the bow make the cord vibrate, giving the note of the entire string. Place the bridge D at the centre of the cord, and the sound will be the *octave* above the former. Thus by taking one-half the length of the cord we double the number of vibrations. Ex.: If an entire cord make 20 vibrations per second, one-half will make 40, and one-third, 60.—The violin or guitar player elevates the pitch of a string by moving his finger, thus shortening the vibrating portion.—In

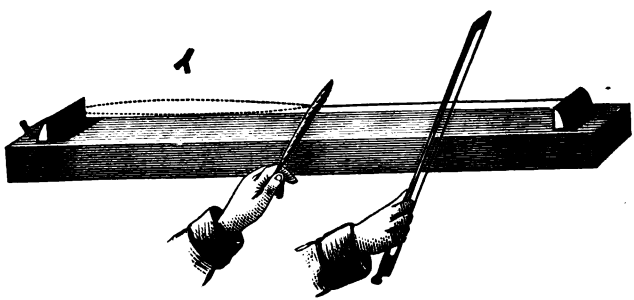
the piano, harp, etc., the long and the short strings produce the low and the high notes respectively.

II. *The number of vibrations per second increases as the square root of the tension.* The cord when stretched by 1 lb. gives a certain tone. To double the number of vibrations and obtain the octave requires 4 lbs. Stringed instruments are provided with keys, by which the tension of the cord and the corresponding pitch may be increased or diminished.

III. *The number of vibrations per second decreases as the square root of the weight of the cord increases.* If two strings of the same material be equally stretched, and one have four times the weight of the other, it will vibrate only half as often. In the violin the bass notes are produced by the thick strings. In the piano fine wire is coiled around the heavy strings.

(3.) NODES.—In these experiments, the cord is shortened by a movable bridge which holds it firmly. If, instead, we

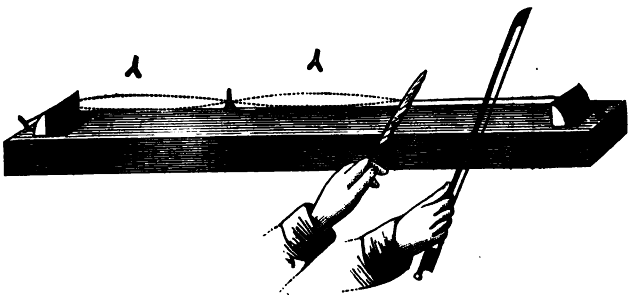
FIG. 127.



rest a feather lightly on the string, and draw the bow over one-half, the cord will vibrate in two portions and give the octave as before. Remove the feather, and it will continue to vibrate in two parts and to yield the same tone. We can show that the second half vibrates by placing across that portion a little paper rider. On drawing the bow it will be

thrown off. Hold the feather so as to separate one-third of the string and cause it to vibrate; the remainder of the cord will vibrate in two segments. When the feather is removed,

FIG. 128.



the entire cord will vibrate in three different parts of equal length, separated by stationary points called *nodes*. This may be shown by the riders; the one at the node remains, while the others are thrown off.

(4.) ACOUSTIC FIGURES.—Sprinkle fine sand on a metal plate. Place the finger-nail on one edge to stop the vibration at that point, as the feather did in the last experiment, and draw the bow lightly across the opposite edge. The sand will be tossed away from the vibrating parts of the plate and will collect along the nodal lines, which divide the large square. It is wonderful to see how the sand will seemingly start into life and dance into line at the touch of

FIG. 129.

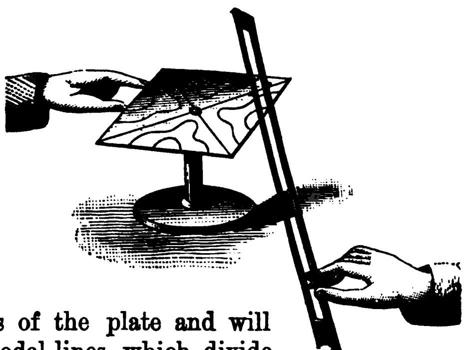
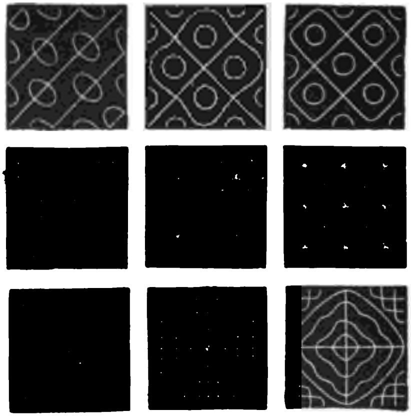


FIG. 130.

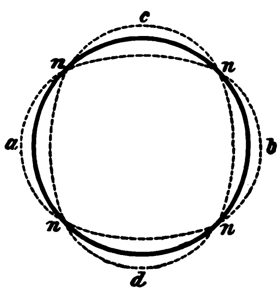


the bow. Fig. 130 shows some of the beautiful patterns obtained by Chladni.

(5.) HARMONICS.* —Whenever a cord vibrates, it separates into segments at the same time. Thus we have the full or *fundamental* note of the entire string, and superposed upon it the higher notes produced by the vibrating parts. These are called *overtones* or *harmonics*. The mingling of the two classes of vibrations determines the *quality* of the sound, and enables us to distinguish the music of different instruments.

(6.) NODES OF A BELL.—Let the heavy circle in Fig. 131 represent the circumference of a bell when at rest. Let the hammer strike at *a*, *b*, *c*, or *d*. At one moment, as the bell vibrates, it forms an oval with *ab*, at the next with *cd*, for its longest diameter. When it strikes its deepest note, the bell vibrates in four segments, with *n*, *n*, *n*, *n*, as the

FIG. 131.



* Press gently but firmly down the notes C, G, and C, in the octave above middle C, on the piano-forte. Without releasing these keys, give to C below middle C a quick, hard blow. The damper will fall, and the sound will stop abruptly. At the same instant a low, soft chord will be heard. This comes from the three strings whose dampers are raised, leaving them free to sound in sympathy with the overtones of the lower C, which sounds are identical with their own.—When a goblet or wine-glass is tapped with a knife-blade, we can distinguish three sounds, the fundamental and two harmonics.

nodal points, whence nodal lines run up from the edge to the crown of the bell. It tends, however, to divide into a greater number of segments, especially if it is very thin, and to produce harmonics. The overtones which follow the deep tones of the bell are frequently very striking, even in a common call-bell.

(7.) NODES OF A SOUNDING-BOARD.—The case of a violin or guitar is composed of thin wooden plates which divide into vibrating segments, separated by nodal lines according to the pitch of the note played. The enclosed air vibrating in unison with these, reinforces the sound and gives it fullness and richness.

(8.) MUSICAL SCALE.—The tone produced by an entire string is called its *fundamental* sound. The notes of the scale above this are given by the parts of the string indicated by the following fractions:

C,	D,	E,	F,	G,	A,	B,	C.
1	$\frac{8}{9}$	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{3}{5}$	$\frac{8}{15}$	$\frac{1}{2}$

As the number of vibrations varies inversely as the length of the cord, we need only to invert these fractions to obtain the relative number of vibrations per second; thus, $\frac{9}{8}$, $\frac{5}{4}$, $\frac{4}{3}$, $\frac{3}{2}$, $\frac{5}{3}$, $\frac{15}{8}$, 2. Reduced to a common denominator, their numerators are proportional, and we have the whole numbers which represent the relative rates of vibration of the notes of the scale, viz.:

24, 27, 30, 32, 36, 40, 45, 48.

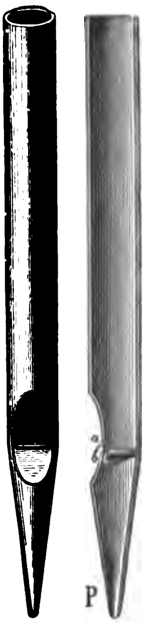
The number of vibrations corresponding to the different letters is,*

C,	D,	E,	F,	G,	A,	B,	C.
128,	144,	160,	170,	192,	214,	240,	256.

* In this table, "C = 256 vibrations" represents the middle C of a piano-forte. This number is purely arbitrary. The so-called "concert-pitch" varies in different countries. The Stuttgart Congress of 1834 fixed the standard tuning-fork—middle A—at 440 vibrations per second, which would make middle C = 264; while the Paris Conservatory (1859) gave to middle A 437.5, and to middle C 261. The English tuning-fork represents C in the treble staff, and makes 528 vibrations, the pitch being the same as the Stuttgart. The ratio of the different letters is identical, whatever the pitch.

8. Wind Instruments produce musical sounds by enclosed columns of air. Sound-waves run backward and forward through the tube and act on the surrounding air like the vibrations of a cord. The sound-waves in organ-pipes are set in motion by either fixed mouth-pieces or vibrating reeds. The air is forced from the bellows into the tube P, through the vent *i*, and striking against the thin edge *a*, produces a flutter. The column of air above, thrown into vibration, reinforces the sound and gives a full musical tone. The length of the pipe determines the pitch. The variation in the quality of different wind instruments is caused by the mingling of the harmonics with the fundamental tone. In the flute, for example, the vibrating column of air may be broken up into segments by varying the force of the breath.

FIG. 182.



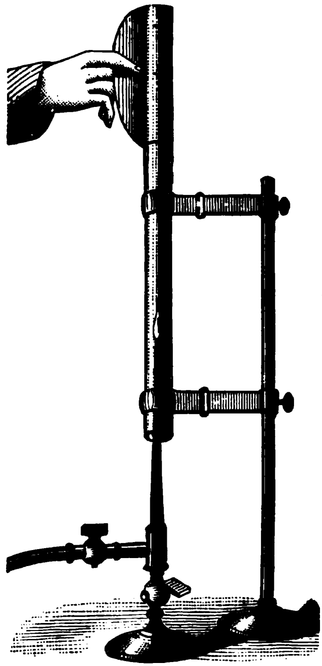
9. Sympathetic Vibrations, or Resonance.—Produce a musical tone with the voice near a piano, and a certain wire will select that sound and respond to it. Change the pitch, and the first string will cease, while another replies. If a hundred tuning-forks of different tones are sounding at the foot of an organ-pipe, it will choose the one to which it can reply, and answer that alone.* Helmholtz has applied this principle to the construction of the *resonance globe*, an instrument which will respond to a particular harmonic in a compound tone, and strengthen it so as to make it audible.

(1.) SENSITIVE FLAMES.—Flames are sensitive to sound. At an instrumental concert the gas-lights vibrate with cer-

* Two clocks set on one shelf or against the same wall, affect each other.—Watches in the shop-window keep better time than when carried singly.—It is said that bell-shaped glasses may be shivered by a powerful voice singing near them the proper note.

tain pulsations of the music. This is noticeable when the pressure of gas is so great that the flame is just on the verge of flaring, and the vibration of the sound-wave is sufficient to "push it over the precipice."*

FIG. 133.



(2.) SINGING FLAMES.—If we lower a glass tube over a small gas-jet, we soon reach a point where the flame leaps spontaneously into song. At first the sound seems far remote, but gradually approaches until it bursts into an almost intolerable scream. The length of the tube and the size of the jet determine the pitch of the note.† The flame, owing to the friction at the mouth of the pipe, is thrown into vibration. The air in the tube, being heated, rises, and not only vibrates in unison with the jet, but, like the organ-pipe, selects the tone corresponding to its length.

10. The Phonograph is an instrument for recording the sound vibrations. It consists of (1) an outer tube (or ear) for receiving the voice vibrations; (2) at the bottom of this a thin plate (or membrane) which vibrates in unison with the voice; (3) at the back of the membrane a

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* Prof. Barrett, of Dublin, describes a peculiar jet which is so sensitive that it trembles and cowers at a hiss, like a human being, beats time to the ticking of a watch, and is violently agitated by the rumpling of a silk dress.

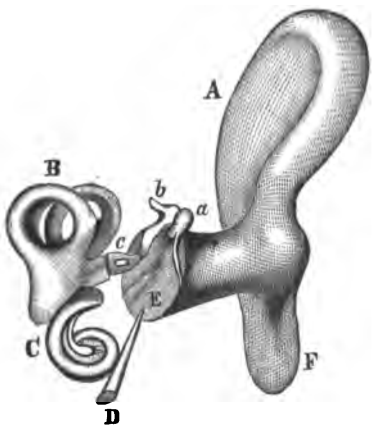
† See *Chemistry*, p. 55. The jets are easily made by drawing out glass tubing to a fine point over a spirit-lamp. The length of the tube may be varied, as in the figure, by a paper tube, *a*.

lever which is moved by these vibrations; (4) at the end of the lever a sharp point, which traces on a sheet of tin-foil marks corresponding to these vibrations; (5) a cylinder wound with a sheet of the foil, and made, by clockwork, to revolve slowly under the pen-point.

After the voice has thus engraved on the foil its vibrations, the cylinder can be reset and the point following the indentations on the foil will move the lever, strike the membrane, and reproduce through an outer tube (or trumpet) the original sound. The sheets of foil may be taken from the cylinder and kept for any length of time to be used when wanted.

11. The Ear.—In Fig. 134, A F represents the back of the outer ear (*Physiology*, p. 184). The sound-wave passes into the auditory canal, which is about an inch in length, and striking against the membrane of the *tympanum* or drum E, which closes the orifice of the external ear, throws it into vibration. Next, the series of small bones, *a, b, c,* called respectively, from their peculiar form, the *hammer, anvil,* and *stirrup,* conduct the motion to the inner ear, which is termed, from its complicated structure, the *labyrinth.* This is filled with liquid, and contains the *semi-circular canals,* B, and the *cochlea* (*snail-shell*), C, which receive the vibrations and transmit them to the auditory nerve, the fine filaments of which are spread out to catch every pulsation of the sound-wave. The middle ear, which contains the chain of small

FIG. 134.



bones, is a cavity about half an inch in diameter, filled with air, communicating with the mouth by the *Eustachian tube*, D.* Within the labyrinth are fine, elastic hair-bristles and crystalline particles among the nerve-fibres, wonderfully fitted, the one to receive and the other to prolong the vibrations; and lastly, a lute of 3,000 microscopic strings, so stretched as to vibrate in unison with any sound.

(1.) Range of the Ear.—Helmholtz fixes the highest limit of musical sounds at 38,000 vibrations per second, and the lowest at 16.† Below this number the pulses cease to link themselves, and become distinct sounds.‡ The range of the ear is thus about eleven octaves. The capacity to hear the higher tones varies in different persons. A sound audible to one may be silence to another. Some ears cannot distinguish the squeak of a bat or the chirp of a cricket, while others are acutely sensitive to these shrill sounds. Indeed, the auditory nerve seems generally more alive to the short, quick vibrations than to the long, slow ones. The whirr of a locust is much more noticeable than the sighing of the wind through the trees.§

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* The Eustachian tube serves to connect the inner cavity with the external atmosphere. If at any time the pressure of the air without becomes greater or less than that within, the membrane of the tympanum feels the strain, pain is experienced, and partial deafness ensues. A forcible concussion frequently produces this result. In the act of swallowing, the tube is opened and the equilibrium restored. We may force air into the cavity of the ear by closing the mouth and nose, and forcibly expiring the air from the lungs. This will render us insensible to low sounds, as the rumble of a railway-train, while we can hear the higher ones as usual.

† A tone produced by about 16 vibrations per second may be made by inserting the finger lightly in the ear, bringing at the same time the muscles of the hand into strong contraction. A sound will be heard which is as deep as the toll of a cathedral bell.

‡ Our unconsciousness is no proof of the absence of sound. There are, doubtless, sounds in Nature of which we have no conception. Could our sense be quickened, what celestial harmony might thrill us! Prof. Cooke beautifully says: "The very air around us may be resounding with the hallelujahs of the heavenly host; while our dull ears hear nothing but the feeble accents of our broken prayers."

§ To this, however, there are remarkable exceptions. The author knows a lady who is insensible to the higher tones of the voice, but acutely sensitive to the lower ones. Thus, on one occasion, being in a distant room, she did not notice the ringing of the bell announcing dinner, but heard the noise the bell made when returned to its place on the shelf.

(2.) **The ability of the ear to detect and analyze sound** is wonderful beyond comprehension. Sound-waves chase one another up and down through the air, superposed in entangled pulsations, yet a cylinder not larger than a quill conveys them to the ear, and each string of that wonderful harp selects its appropriate sound, and repeats the music to the soul within. Though a thousand instruments be played at once, there is no confusion, but each is heard, and all blend in harmony.*

PRACTICAL QUESTIONS.—1. Why cannot the rear of a long column of soldiers keep time to the music in front? 2. Three minutes elapse between the flash and the report of a thunderbolt; how far distant is it? 3. Five seconds expire between the flash and the report of a gun; what is its distance? 4. Suppose a speaking-tube should connect two villages ten miles apart; how long would it take the sound to travel? 5. The report of a pistol-shot was returned to the ear from the face of a cliff in four seconds; what was the distance? 6. What is the cause of the difference between the voice of man and woman? A base and a tenor voice? 7. What is the number of vibrations per second necessary to produce the fifth tone of the scale of C? 8. What is the length of each sound-wave in that tone when the temperature is at zero? 9. What is the number of vibrations in the fourth tone above middle C? 10. A meteor of Nov. 13, 1868, exploded at a height of 60 miles; what time was needed for its sound to reach the earth? 11. A stone is let fall into a well, and in four seconds is heard to strike the bottom; how deep is the well? 12. What time would be required for a sound to travel five miles in the still water of a lake? 13. How much louder will be the report of a gun to an observer at a distance of 20 rods than to one at half a mile? 14. Does sound travel faster at the foot than at the top of a mountain? 15. Why is an echo weaker than the original sound? 16. Why is it so fatiguing to talk through a speaking-trumpet? 17. Why will the report of a cannon fired in a valley be heard on the top of a neighboring mountain, better than one fired on the top of a mountain will be heard in the valley? 18. Why do our footsteps in unfurnished dwellings sound so startlingly distinct? 19. Why do the echoes of an empty church disappear when the audience assemble? 20. What is the object of the sounding-board of a piano? 21. During some experiments, Tyndall found that a certain sound would pass through twelve folds of a dry silk handkerchief, but would be stopped by a single fold of a wet one. Explain. 22. What is the cause of the musical murmur often heard near telegraph lines? 23. Why will a variation in the quantity of water in the goblet, when made to sound, in the experiment described on p. 123, cause a difference in the tone? 24. At what rate (in metres) will sound move through air, the temperature being 20° C.?

* "Is not the ear the most perfect sense? A needlewoman will distinguish by the sound whether it is silk or cotton that is torn. Blind people recognize the age of persons by their voices. An architect, comparing the length of two lines separated from each other, if he estimate within $\frac{1}{30}$, we deem very accurate; but a musician would not be considered very precise who estimated within a quarter of a note ($128 \div 30 = 4$ nearly). In a large orchestra, the leader will distinguish each note of each instrument. We recognize an old-time friend by the sound of his voice, when the other senses utterly fail to recall him. The musician carries in his ear the idea of the musical key and every tone in the scale, though he is constantly hearing a multitude of sounds. A tune once learned will be remembered when the words of the song are forgotten."

SUMMARY.

Sound is produced by vibrations. These are transmitted in waves through the air (60° F.) at the rate of 1120 feet per second; through water four times, and through iron fifteen times as fast. In general, the velocity depends on the relation between the density and the elasticity of the medium; and the intensity is proportional to the square of the amplitude of the molecular vibrations. Sound, like light, may be reflected and refracted to a focus. Echoes * are produced by the reflection of sound from smooth surfaces, not less than 112 feet (about 33 metres) distant. Rapidly-repeated vibrations make a continuous sound; regular and rapid vibrations produce music; irregular ones cause a noise.

The pitch of a sound depends on the rapidity of the vibrations. The number of waves, and their consequent length in a given sound, is found by means of the siren. Unison is produced by identical wave-motions. Any number of sound-waves may traverse the air, as any number of water-waves may the surface of the sea, without losing their individuality. The motion of each molecule of air is the algebraic sum of the several motions it receives. Two systems of waves may therefore destroy or strengthen each other, according as their several condensations or rarefactions coalesce. Interference is the mutual destruction of two systems of waves. "Beats" is the effect produced by two musical sounds of nearly the same pitch, which alternately interfere and coincide. The vibrations of a cord produce a musical sound, which is reinforced by a sounding-board. The rate of vibration and consequent pitch depends on the length, the tension, and the weight of the cord. Sounding bodies tend to vibrate in segments. The harmonics thus produced give the quality (timbre) of different sounds. The various notes in the musical scale are deter-

* Several acoustic phenomena have become of historical interest. (1.) Near Syracuse, Sicily, is a cave known as the Ear of Dionysius. A whisper at the further end of the cavern is easily heard by a person at the entrance, though the distance is 200 feet. Tradition says that the Tyrant of Syracuse used this as a dungeon, and was thus enabled to listen to the conversation of his unfortunate prisoners. (2.) On the banks of the Nile, near Thebes, is a statue 47 feet high, and extending 7 feet below the ground. It is called the Vocal Memnon. Ancient writers tell us that about sunrise each morning, there issued from this gigantic monolith a musical sound resembling the breaking of a harp-string. It is now believed that this was produced by strong currents of air (due to the change of temperature in the early morning) passing through crevices in the stone. (3.) Near Mount Sinai, in Arabia, remarkable sounds are produced by the sand falling down a declivity. The sand, which is very white, fine and dry, lies at such an angle as to be easily set in motion by any cause, such as scraping away a little at the foot of the slope. The sand then rolls down with a sluggish motion, causing at first a low moan, that gradually swells to a roar like thunder, and finally dies away as the motion ceases.

mined by fixed portions of the length of the cord. The music of a wind-instrument is produced by vibrating columns of air. Resonance is a sympathetic vibration caused by one sonorous body in another, as seen in sensitive flames, the resonance globe, etc. The voice is a reed instrument, with its vibrating cords and resonant cavity. The ear collects the sound-waves and transmits the motion to the brain. It consists of the outer ear, the drum and the labyrinth.

HISTORICAL SKETCH.

The ancients knew that without air we should be plunged in eternal silence. "What is the sound of the voice," cried Seneca, "but the concussion of the air by the shock of the tongue? What sound could be heard except by the elasticity of the aërial fluid? The noise of horns, trumpets, hydraulic organs, is not that explained by the elastic force of the air?" Pythagoras, who lived in the 6th century before Christ, conceived that the celestial spheres are separated from each other by intervals corresponding with the relative lengths of strings arranged to produce harmonious tones. In his musical investigations he used a monochord, the original of the sonometer now employed by physicists, and wished that instrument to be engraved on his tomb. Pythagoras held that the musical intervals depend on mathematics; while his great rival, Aristoxenes, claimed that they should be tested by the ear alone. The theories of these two philosophers long divided the attention of the scientific world.

Many centuries elapsed before any marked advance was made. Galileo called attention to the sonorous waves traversing the surface of a glass of water, when the glass is made to vibrate. Newton believed sound to be transmitted by aërial waves, and estimated the rate.

The present century has witnessed a more complete demonstration of the laws of the vibrations of cords and the general principles of sound. In 1822, Arago, Gay-Lussac and others decided the velocity of sound to be 337 *metres* at 10° C. Savart invented a toothed wheel by which he determined the number of vibrations in a given sound; Latour discovered the siren, which gave still more accurate results; Colladon and Sturm, by a series of experiments at Lake Geneva, found the velocity of sound in water; Helmholtz made known the laws of harmonics; Lissajous, by means of a mirror attached to the vibrating body, threw the vibrations on a screen in a series of curves, and so rendered them visible; while Tyndall has investigated the causes modifying the propagation of sound, as acoustic clouds, fogs, etc., and popularized the whole subject of acoustics. (References, p. 120.)

VII.

ON LIGHT.

The sunbeam comes to the earth as simply motion of ether-waves, yet it is the grand source of beauty and power. Its heat, light, and chemical force work everywhere the miracle of life and motion. In the growing plant, the burning coal, the flying bird, the glaring lightning, the blooming flower, the rushing engine, the roaring cataract, the pattering rain—we see only varied manifestations of this one all-energizing force.

ANALYSIS.

OPTICS

1. PRODUCTION AND TRANSMISSION OF LIGHT.
1. Definitions.
2. Visual Angle.
3. Laws of Light.
4. Velocity of Light.
5. Theory of Light.

2. REFLECTION OF LIGHT.
1. Definition and Law.
2. Action of Rough and Polished Surfaces.
3. Mirrors.
   - (1.) Plane.
     - (a.) *Effect of.*
     - (b.) *Image seen.*
     - (c.) *Image behind mirror.*
     - (d.) *Multiple images.*
     - (e.) *Images in water.*
   - (2.) Concave.
     - (a.) *Effect of.*
     - (b.) *Image seen.*
   - (3.) Convex.
     - (a.) *Effect of.*
     - (b.) *Image seen.*
4. Total Reflection.

3. REFRACTION OF LIGHT.
1. Definition and Illustrations.
2. Laws of Refraction and Illustrations
3. Lenses.
   - (1.) Convex.
     - (a.) *Effect of.*
     - (b.) *Image seen.*
   - (2.) Concave.
     - (a.) *Effect of.*
     - (b.) *Image seen.*
4. Aberration.
5. Mirage.

4. COMPOSITION OF LIGHT.
1. Solar Spectrum.
2. Three Classes of Rays.
3. Three Kinds of Spectra.
4. The Spectroscope.
5. Rainbow.
   - (1.) Formation of.
   - (2.) Primary Bow.
   - (3.) Secondary Bow.
   - (4.) Why the Bow is Circular.
6. Complementary Colors.
7. Interference of Light.
8. Color.
9. Polarization of Light.

5. OPTICAL INSTRUMENTS.
1. Microscope.
2. Telescope.
3. Opera Glass.
4. Stereoscope.
5. Magic Lantern.
6. Camera.
7. Eye.

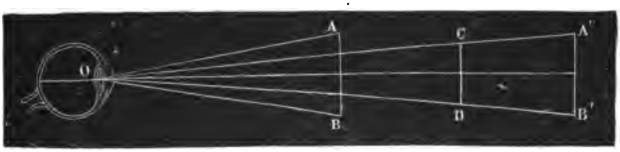
OPTICS, OR THE SCIENCE OF LIGHT.

1. PRODUCTION AND TRANSMISSION OF LIGHT.

1. Definitions.—A *luminous* body is one that emits light. A *medium* is any substance through which light passes. A *transparent* * body is one that obstructs light so little that we can see objects through it. A *translucent* body is one that lets some light pass, but not enough to render objects visible through it. An *opaque* body is one that does not transmit light. A *ray of light* is a single line of light; it may be traced in a dark room into which a sunbeam is admitted by the floating particles of dust which reflect the light to the eye. A *pencil* or *beam of light* is a collection of rays, which may be *parallel, diverging* or *converging.*

2. The Visual Angle is the angle formed at the eye by rays coming from the extremities of an object. The angle AOB is the angle of vision subtended by the object

FIG. 135.



AB. The size of this angle varies with the distance of the body. AB and A′B′ are of the same length, and yet the angle A′OB′ is smaller than AOB, and hence A′B′ will seem

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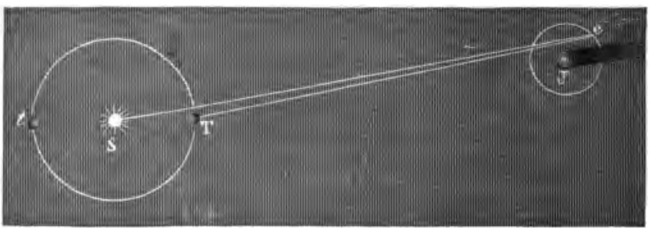
* The terms transparent and opaque are relative. No substance is perfectly transparent, or entirely opaque. Glass obstructs some light. According to Miller 7 feet of the clearest water will arrest one-half the light which falls upon it. While Young asserts that the beam of the setting sun, passing through 200 miles of air, loses [illegible] of its force. On the other hand, gold, beaten into leaf, becomes translucent, and of a faint green color; and scraped horn is semi-transparent.

shorter than AB. The distance and the size of objects are intimately connected, since by experience we have learned to associate them. Knowing the distance of an object, we immediately determine its size from the visual angle.*

3. Laws of Light.—I. Light passes off from a luminous body equally in every direction. II. Light travels through a uniform medium in straight lines. III. The intensity of light decreases as the square of the distance increases.

4. The Velocity of Light has been determined in various ways. The following was the first method: The planet Jupiter has four moons. As these revolve around the planet, they are eclipsed at regular intervals. In the cut, let J represent Jupiter, *e* one of the moons, S the sun,

FIG. 136.



and T and *t* different positions of the earth in its orbit around the sun. When the earth is at T, the eclipse occurs 16 min. and 36 sec. earlier than at *t*. That interval of time is required for the light to travel across the earth's orbit, giving a velocity of about 186,000 miles per second.†

5. Undulatory Theory of Light.—There is supposed to be a fluid, termed *ether*, constituting a kind of universal atmosphere, diffused through space. It is so subtle that it

* We can *vary the apparent size of any body at which we are looking by increasing or diminishing this angle*—a principle that will be found of great importance in the formation of images by mirrors and lenses.

† This rate is so great that for all distances on the earth it is instantaneous. A sunbeam would girt the globe quicker than we can wink.

glides among the molecules of bodies as the air does among the branches and the foliage of trees. It fills the pores of all substances, eludes all chemical tests, passes in through the receiver, and remains even in the vacuum of an air-pump. A luminous body sets in motion waves of ether, which go off in every direction. They move at the rate of 186,000 miles per second, and breaking upon the eye, give the impression of sight. The wave-motion is like that of sound, except the vibrations are *transverse* (crosswise).*

2. REFLECTION OF LIGHT.

1. Definition.—Light falling on a surface is divided into two portions. One enters the body; the other is reflected † according to the familiar law of Motion and of Sound: The angle of incidence = that of reflection.

2. Action of Rough and Polished Surfaces.—When the surface is rough, the numerous little elevations scatter the reflected rays in every direction, forming *diffused* light. Such a body can be seen from any point. When the surface is polished, the rays are uniformly reflected in particular directions, and bring to us the images of other objects. We thus see non-luminous objects by irregularly-reflected (diffused) light, and images of objects by regularly-reflected light.‡

3. Mirrors.—All highly-reflecting surfaces are mirrors. These are of three kinds—*plane, concave* and *convex*. The

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* Thus, if we suppose a star directly overhead and a ray of light coming down to us, we should conceive that the particles which compose the waves are vibrating N. S. E. W., and toward every other point of the compass all at once.

† The amount of light reflected varies with the angle at which light falls. Thus, if we look at the images of objects in still water, we notice that those near us are not as distinct as those on the opposite bank. The rays from the latter striking the water more obliquely are more perfectly reflected to the eye.—Fill a sheet-iron or any dark-colored pail with water tinted with bluing or red ink. The color will be quite invisible to a spectator at a little distance. Now insert in the water a plate. This will reflect the transmitted light and reveal the hue of the water.

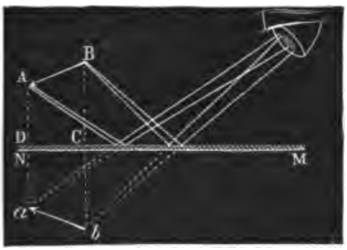
‡ The most perfectly polished substance, however, diffuses some light—enough to enable us to trace its surface; were it not so, we should not be aware of its existence. The deception of a large plate-glass mirror is often nearly complete; but dust or vapor, increasing the irregular reflection, will bring its surface to view.

first has a flat surface; the second, one like the inside, and the third, one like the outside of a watch-crystal. The general principle of mirrors is that *the image is seen in the direction of the reflected ray as it enters the eye.*

(1.) PLANE MIRRORS.—Rays of light retain their relative direction after reflection from a plane surface.* An image seen in a plane mirror is therefore erect and of the same size as the object. It is, however, reversed right and left.

Why the image is as far behind the mirror as the object is in front. Let AB be an arrow held in front of the mirror MN. Rays of light from the point A striking upon the mirror at C, are reflected, and enter the eye as if they came from *a*. Rays from B seem to come from *b*. Since the image is seen in the direction of the reflected rays, it appears at *ab*, a point which can easily be proved to be as far behind MN as the arrow is in front of it. Such an image is called a *virtual* one, as it has no real existence.

FIG. 137.



Why we can see several images of an object in a mirror. Metallic mirrors form only a single image. If, however, we look obliquely at the image of a candle in a looking-glass, we shall see several images, the first feeble, the next bright, and the others diminishing in intensity. The ray from A is in part reflected to the eye from the glass at *b*, and gives rise to the image *a*; the remainder passes on and is reflected from the metallic surface

FIG. 138.

* The perpendiculars are not given in the figures of the book, as *the pupil at recitation should draw all the cuts on the blackboard, erect the perpendiculars and demonstrate the location of the reflected ray.* It will aid in drawing the perpendicular to a

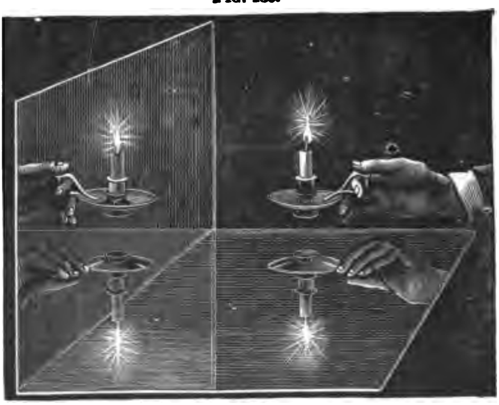
at c, and coming to the eye forms a second image a'. The ray cd, when leaving the glass at d, loses a part, which is reflected back to form a third image. This ray in turn is divided to form a fourth, and so on.*

Images seen in water are symmetrical, but inverted. The reason of this can be understood by holding an object in front of a horizontal looking-glass and noticing the angle at which the rays must strike the surface in order to be reflected to the eye. When the moon is high in the heavens, we see the image in the water at only one spot, while the rest of the surface appears dark. The light falls upon all parts, but the rays are reflected from only one point at the

convex or concave surface, to remember that it is a radius of the sphere of which the mirror forms a part. A book held in various positions before a looking-glass illustrates the action of plane mirrors. A beam of light admitted into a dark room and reflected from a mirror will show that the angles of incidence and reflection are in the same plane. Many of the grotesque effects of concave and convex mirrors may be seen on the inner and outer surfaces of a bright spoon, call-bell, or metal cup (see *Mayer & Barnard's Light* for inexpensive experiments).

* To illustrate the formation of multiple images, place two small mirrors as in Fig. 189, where two coincident images are produced by second partial reflections. To vary the experiment hold the mirrors together like the covers of a book placed on end, and put the candle between them on the table, opening and shutting the mirror-cover so as to vary the angle; or hold the mirrors parallel to each other with the light between them. When the mirrors are inclined at 90°, three images are formed; at 60°, five images; and at 45°, seven images. As the angle increases, the number diminishes. The images are upon the circumference of a circle whose centre is on a line in which the reflecting surfaces would intersect if produced. Where the mirrors are parallel the images are in a straight line. They become dimmer as they recede, light being lost at each reflection.—The *Kaleidoscope* contains three mirrors set at an angle of 60°. Small bits of colored glass at one end reflect to the eye at the other multiple images which change in varying patterns as the tube is revolved.

FIG. 189.



right angle to reach the eye. Each observer sees the image at a different place. When the surface of the water is ruf-

FIG. 140.

fled, a tremulous line of light is reflected from the side of each tiny wave that is turned towards us. As every little billow rises, it flashes a gleam of light to our eyes, and then sinking, comes up beyond, to reflect another ray.

FIG. 141.

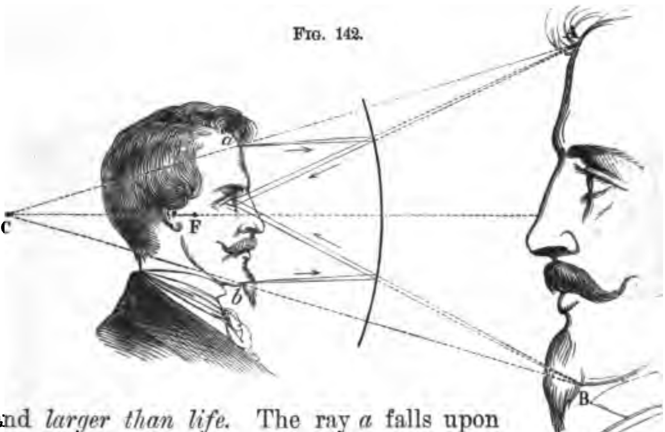
(2.) A CONCAVE MIRROR *tends to collect the rays of light.** Thus in Fig. 141, parallel rays falling upon the mir-

* This statement is convenient as it is true in the practical use of the mirror, but does not obtain in every possible position. Thus, if a light be placed between A and F the rays would be scattered, as can easily be shown by a diagram. Again, in elementary optics it is supposed that MCN, known as the *angular aperture* of the mirror, does not exceed 8° or 10°. When greater, the rays reflected near the edge of the mirror meet the *principal axis* AL, nearer the mirror than F. This is called the *aberration* of the mirror (p. 161). The reflected rays will then cross at points in a curved surface called a *caustic*. A section of such a curve can be seen when the light of a candle is reflected from the inside of a cup partly full of milk.

ror MN are reflected to the point F, the ***principal focus*** (*focus*, a hearth). This is half way between the mirror and C, the ***centre of curvature,*** i. e. the centre of the hollow sphere of which the mirror is a part. AF is the ***focal*** distance; CB, CD, etc., are radii of the sphere (perpendiculars, to find the angle of incidence); and the angles HBC, GDC, etc., are equal respectively to FBC, FDC, etc. A light held at C will have its rays brought to a focus at C, where a ***real*** image will be formed; while one at F will be reflected in a beam of parallel rays.

Images formed by concave mirrors. Hang a concave mirror against the wall, and stand closely to it between the mirror and the principal focus. The image is ***erect, virtual,***

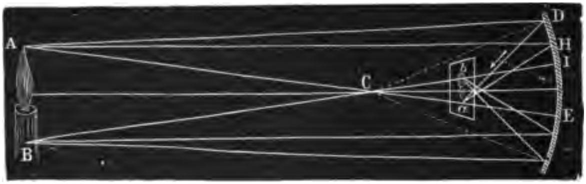
Fig. 142.



and *larger than life.* The ray *a* falls upon the mirror, is reflected and strikes the eye as if it came from A. In the same manner *b* is seen at B. The visual angle is increased the nearer we approach the mirror, and hence the larger the image appears. We now walk back. When we reach the focus, the image disappears. We are in the position of the candle *ab* (Fig. 143) and the real image is behind us at AB. A few of the parallel rays, however, enter the eye, and an indistinct image is formed. Retiring still further, we come to the centre of curvature. Here we find no distinct image, although por-

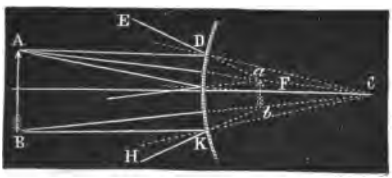
tions of our figure, as we catch snatches of the rays forming the image AB, are seen grotesquely magnified. As we continue to recede, we reach a point beyond the centre of

FIG. 143.



curvature. Here we occupy the position AB (Fig. 143), and see the image at *ab* inverted, as the rays have crossed. The points occupied by the two candles, *ab* and AB, are termed *conjugate foci*, because a light at either one is brought to a focus at the other.

FIG. 144.



(3.) A CONVEX MIRROR *tends to scatter the rays of light.* The parallel rays AD and BK (Fig. 144), are reflected in the diverging lines DE and KH. An eye receiving these rays will perceive the image of AB at *ab, virtual, erect,* and *smaller than life.* Whatever may be the position of the object, the image being always between the object and the centre of curvature is smaller than the object.

FIG. 145.

4. Total Reflection.—When we look obliquely into a

pond, we cannot see the bottom, because the rays of light from below are reflected downward at the surface of the water. Hold a glass of water above the level of the eye, and the upper part will gleam like burnished silver.* Thus the internal surface of a transparent body becomes a mirror. This occurs when light would pass very obliquely from a denser to a rarer medium.

3. REFRACTION OF LIGHT.

1. Definition.—When a ray of light passes obliquely from one medium to another of different density, it is *refracted* or bent out of its course. Ex.: A spoon in clear tea appears bent.—An oar dipping in still water seems to break at the point where it enters the water.†—Put a cent in a bowl. Standing where you cannot see the coin, let another person pour water into the vessel, when the coin

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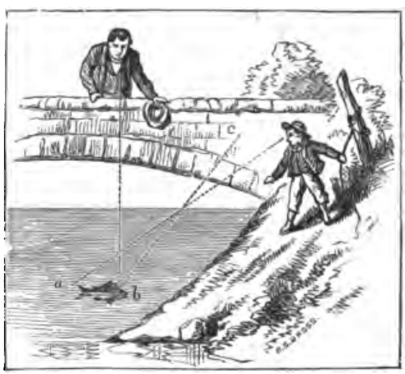
* Place a bright spoon in the glass and notice its image reflected from the surface of the water. The apparently increased size of the spoon, the broken handle, etc., will be understood after reading the next subject. Turn the spoon about in the glass and, changing the angle of observation, notice the effect. The real handle may apparently be attached to the image in the water. The spoon will soon be covered with bubbles of air shining, like pearls, from total reflection. This shows also the presence of air in water and the adhesion of gases to solids. The goblet, if filled with cold water, will "sweat," as it is called, from the condensed moisture of the atmosphere.

Fig. 146.



† Fish seem nearer the surface than they really are, and Indians, who spear them, try to strike perpendicularly, or else aim lower than they apparently lie.—In Fig. 146, the man on the bridge sees the fish in its true place: but the boy on the bank sees the fish at *a*, while the fish sees the boy at *c*.—Water is deeper than it appears. Look obliquely into a pail of water, then place your finger on the outside where the bottom seems to be; you will be surprised to find the real bottom is several inches below.—Fill a glass dish with water, and, darkening the windows, let a sunbeam fall upon the surface. The ray will bend as it enters. Dust scattered through the air will make the beam distinct.

will be lifted into view. To understand the apparent change of position, remember that *the object is seen in the direction of the refracted ray as it enters the eye.* Let L, Fig. 148, be a body beneath the water. A ray, LA, coming to the surface, is bent downward toward C, and strikes the eye as if it came from L′. The object will therefore apparently be elevated above its true place.

FIG. 147.

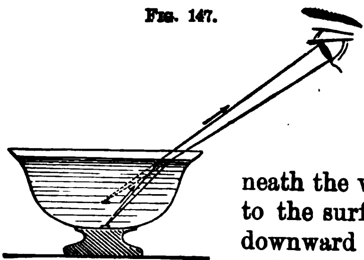
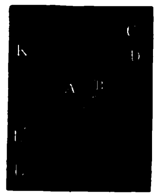


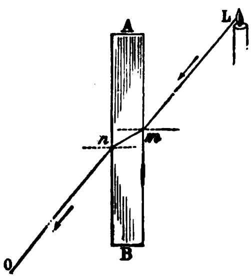
FIG. 148.



2. Laws of Refraction.—I. In passing into a rarer medium, the ray is bent *from* the perpendicular. II. In passing into a denser medium, the ray is bent *toward* the perpendicular.*

ILLUSTRATIONS.—*Path of rays through a window-glass.*—When a ray enters a window-glass, it is refracted toward the perpendicular (2d law), and on leaving, is refracted from the perpendicular (1st law). The general direction of objects is therefore unchanged. A poor quality of glass produces distortion by its unequal density and uneven surface.

FIG. 149.

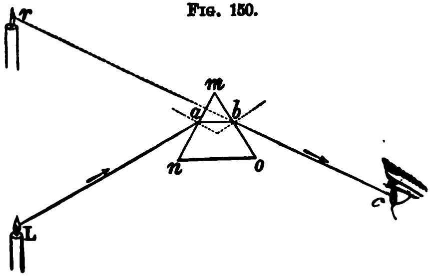


Path of rays through a prism. A ray of light, on entering and on leaving a prism, is refracted as by a window-glass. The inclination of the sides causes the ray

* Both the incident and the refracted ray lie in the same plane as the normal (perpendicular). The ratio between the sines of the incident and refracted angles is termed the *index of refraction*. It varies with the media. Ex.: From air to water it is $\frac{4}{3}$ and from air to glass $\frac{3}{2}$.

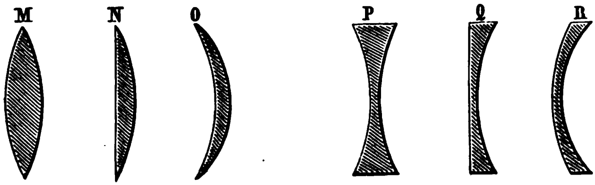
to be *bent twice in the same direction.* The candle L will therefore appear to be at *r*.

Fig. 150.



3. Lenses —A lens is a transparent body, with at least one curved surface. There are two general classes of lenses, *concave* and *convex.** (See Fig. 151.)

Fig. 151.



(1.) The double-convex lens has two convex surfaces. Its action on light is like that of a concave mirror. A ray

Fig. 152.

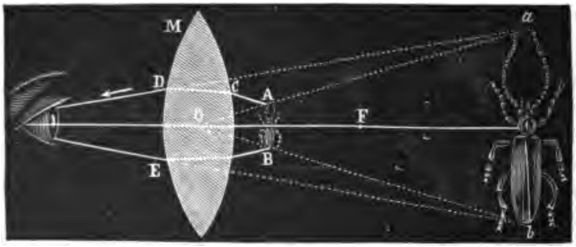
X striking perpendicularly, is not refracted. The parallel rays M, L, etc., are refracted both on entering and on leaving the lens, and are converged at F, the *focus.*† If a light be placed at F, its rays will be made parallel.

* Forms of lenses: M, double-convex; N, plano-convex; O, meniscus (crescent); P, double-concave; Q, plano-concave; R, concavo-convex. The first three are styled *magnifiers*, and the second, *diminishers*.

† The convex lens is sometimes termed a *burning-glass*, being used, like the

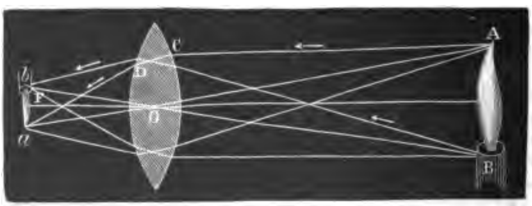
The image formed by a convex lens is like that of a concave mirror. If we hold a lens above a printed page, when we obtain the focal distance correctly, we shall find the let-

FIG. 153.



ters right-side up and highly magnified. In Fig. 153 we see how the converging power of the lens increases the visual angle, and makes the object AB appear the size *ab*.

FIG. 154.



Moving the lens back from the page, the letters entirely disappear as we pass the principal focus. At length they reappear again, but smaller and inverted (Fig. 154).

(2.) THE DOUBLE-CONCAVE LENS has two concave surfaces. Its action on light is like that of a convex mirror. Thus, diverging rays from L (Fig. 155) are rendered more diverging, and, to an eye which receives the rays MN, the candle would seem to be at *l*, where the image is seen.

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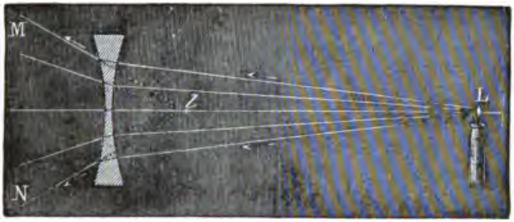
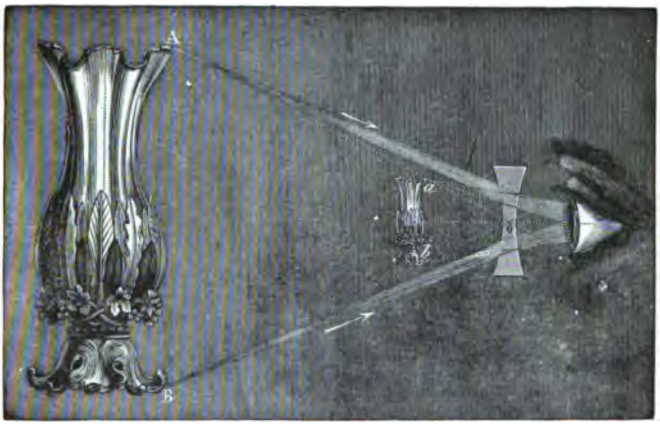
concave mirror, for collecting the sun's rays. Lenses have been manufactured of sufficient power to melt a stone almost instantly. Even glass-globes of water, such as are used for gold fishes or in the windows of drug stores, often fire adjacent objects.

FIG. 155.



The image formed by a concave lens, like that of a convex mirror, is virtual, erect, and diminished in size (Fig. 156).

FIG. 156.



4. Aberration.—Rays which pass through a lens near the edge are brought to a focus sooner than those near the centre. Therefore, when the border of an image is clear, the centre will be indistinct, and *vice versa*. This wandering of the rays from the focus is termed *spherical aberration.* The different refrangibility of the colors which compose white light (p. 163) produces *chromatic aberration.* The violet, being bent most, comes to a focus sooner than the red, which is bent least. This causes the play of colors seen around the image produced by an ordinary lens. The defect

is remedied by a second lens of different dispersive power, which counteracts the effect of the first. Such a compound lens is said to be *achromatic* (colorless).

5. Mirage.—In the heated deserts of Africa, the traveller sometimes sees in the distance quiet lakes with the shadows of trees in their cool waters. Rushing forward to slake his eager thirst, he finds only the barren waste of sand. The mariner often recognizes in the sky the images of ships, and the far-distant coast, with its familiar cliffs. The cause of these phenomena is the refraction and reflection of the rays of light traversing layers of air of unequal density.

FIG. 157.

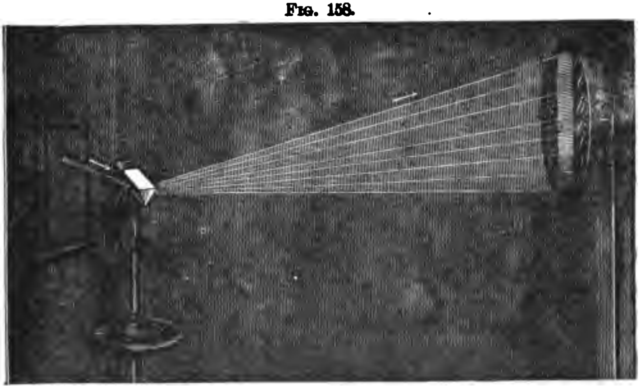
Sometimes a layer of air high up in the sky acts as a reflector, and sends down inverted images of ships which are beyond the horizon. In Fig. 157, rays of light from a clump of trees are refracted more and more until finally they are reflected from a layer at *a*, and enter the eye of the Arab as if they came from the surface of a quiet lake. The deception is made complete by the fact that the sandy desert, shimmering in the hot sun, often has in the distance the aspect of tranquil water.*

* Hold a pane of glass horizontally above the eyes. The inverted images of objects in front may be seen, reflected from the surface of the glass.

4. THE COMPOSITION OF LIGHT.

1. Solar Spectrum.—When a sunbeam shines through a prism, the ray is not only bent from its course, but is also spread out, fan-like, into a band of rainbow-colors—the *solar spectrum.* It contains the seven primary colors—*violet, indigo, blue, green, yellow, orange, red.** If we receive the spectrum on a concave mirror, or pass it through a convex lens, it will form a white spot. We therefore conclude that white light is composed of seven colors. They are separated because the prism bends them unequally. The violet is most refracted, and the red least.

FIG. 158.

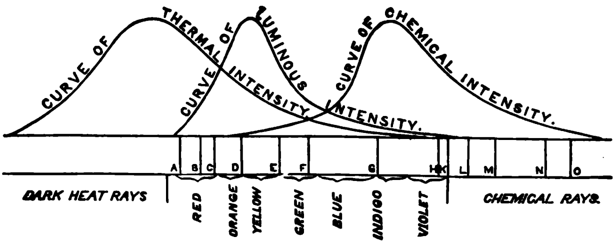


2. Three classes of rays exist in the solar spectrum; viz.: the *calorific,* or heat-rays; *colorific,* or luminous rays; and *actinic,* or chemical rays.† If we examine the spectrum with a delicate thermometer, we find that the heat increases from the violet to the red, and becomes the greatest in the dark space just beyond. If we test with a paper

* Notice that the initial letters spell the mnemonic word, *Vib-gy-or.*

† The classification into three kinds of rays is retained as it is still common in scientific books. Draper has shown that the effects described above are due merely to an unequal distribution of the ether-waves by the prism. Rays of all colors have the same light, heat, and chemical power, and the same cause—*radiant energy.* We call this one thing, light, heat, or actinism, according to the means used to reveal its presence (pp. 183-4).

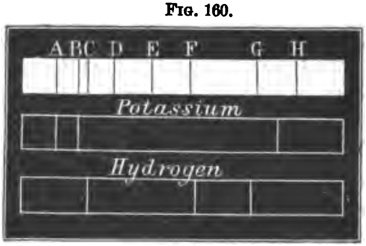
FIG. 159.



containing chloride of silver, it will blacken least in the red, most toward the violet, and some in the dark space beyond. Between these two extremes lie the rays which strongly affect the eye.

3. Three Kinds of Spectra.—I. When the light of a solid or liquid body, as iron white-hot, is passed through a prism, the *spectrum is continuous* and consists of the familiar colors of the rainbow. II. When the light of a burning gas is passed through a prism, the *spectrum is not continuous,* but consists of bright-colored lines—copper giving a set of green lines, and zinc one of bright blue and red. Each element produces a series which can be recognized as its test. III. When a light of the first kind is passed through one of the second at a lower temperature, the *spectrum is crossed by dark lines.* Thus, when the white light of a burning match shines through a flame containing sodium, instead of the two vivid yellow lines so characteristic of that metal, two black lines occupy their place. In general, a gaseous flame absorbs rays of the same color that it emits.*

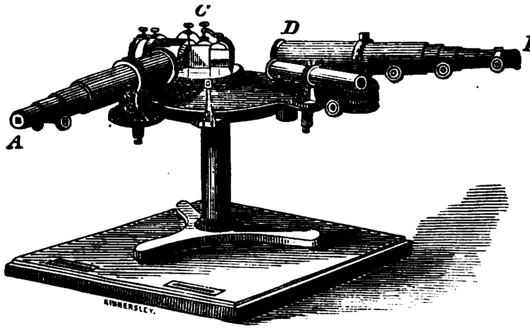
FIG. 160.



* Imagine a room filled with piano-wires, stretched in every direction and tuned to one key. Now let a person at one end of the room play a tune. Another per-

4. The Spectroscope is an instrument for examining spectra. The rays of light (Fig. 161) enter through a narrow slit in the tube at A, and are rendered parallel by an object-glass. They then pass through the prisms at C, are

FIG. 161.



separated into the different colors, and entering the telescope at D, fall upon the eye at B. Any substance may be placed in the flame in front of A and its spectrum examined.*

5. The Rainbow is formed by the *refraction* and *reflection* of the sunbeam in drops of falling water. The white light is thus decomposed into its simple colors. The

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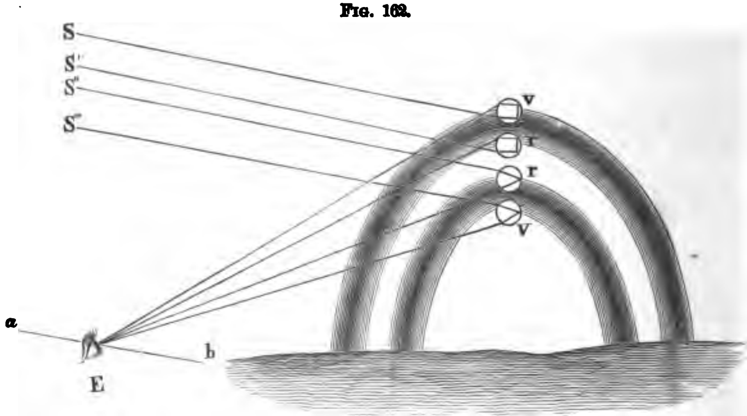
son at the opposite end of the room would hear the tune perfectly except when the particular note which belonged to the wires was struck, when that would be sifted out.

* On the uses of the spectroscope, examine *Astronomy*, p. 286, and *Chemistry*, p. 145. The frontispiece of the latter gives a colored illustration of the spectra.—The solar spectrum is crossed by dark lines known as *Fraunhofer's lines*. The most prominent are marked for convenience of reference (A, B, C, etc., Fig. 160). The spectroscope affords an unrivalled mode of analysis. No chemical test is so delicate. Strike together two books near the light at the slit of the spectroscope, and the dust blown into the flame will contain enough sodium (the basis of common salt) to cause the yellow D lines—its test—to flash out distinctly. (See note on spectroscope, p. 226.) A very effective spectroscope may be contrived thus: Cut a slit not over $\frac{1}{16}$ inch wide and 2 inches long in a piece of tinfoil, and gum it on a pane of glass. Hold this before a flame and look at it through a prism.

inner arch is termed the primary bow; the outer or fainter arch, the secondary.

PRIMARY BOW.—A ray of light, S″, enters, and is bent downward at the top of a falling drop, passes to the opposite side, is there reflected, then passing out of the lower side, is bent upward. By the refraction the ray of white light is decomposed, so that when it emerges it is spread out fan-like, as in the solar spectrum. Suppose that the eye of a spectator is in a proper position to receive the red ray, he cannot receive any other color from the same drop, because the red is bent upward the least, and all the others will pass directly over his head. He sees the violet in a drop below. Intermediate drops furnish the other colors of the spectrum.

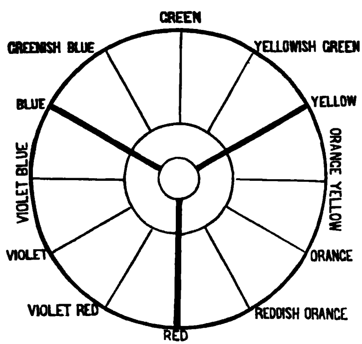
FIG. 162.



SECONDARY BOW.—A ray of light, S, strikes the bottom of a drop, *v*, is refracted upward, passes to the opposite side, where it is twice reflected, and thence passes out at the upper side of the drop. The violet ray being most refracted, is bent down to the eye of the spectator. Another drop, *r*, refracting another ray of light, is in the right position to send the red ray to the eye.

WHY THE BOW IS CIRCULAR.—When the red ray of the primary bow leaves the drop, it forms an angle with the sun's ray, S″*r*, of about 42°, and the violet 40°. These angles are constant. Let *ab* be a straight line drawn from the sun through the observer's eye. If produced, it would pass through the centre of the circle of which the rainbow is an arc. This line is termed the *visual axis.* It is parallel to the rays of the sun; and when it is also parallel to the horizon, the rainbow is a semicircle. Suppose the line E*v* in the primary bow to be revolved around E*b*, keeping the angle *b*E*v* unchanged; the point *v* would describe a circle on the sky, and every drop over which it passed would be at the proper angle to send a violet ray to the eye at E. Imagine the same with the drop *r*. We can thus see (*a*) the bow must be circular; (*b*) when the sun is high in the heavens, the whole bow sinks below the horizon; (*c*) the lower the sun the larger is the visible circumference; and (*d*) on lofty mountains a perfect circle may sometimes be seen.*

FIG. 163.



6. Complementary Colors.—Two colors, which by their mixture produce white light, are termed complementary to each other. Thus, if we sift the red rays out of a beam of light and bring the remainder to a focus, a green image will be formed.† In Fig. 163 the colors opposite each other are complementary. Place a red and a

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* Halos, coronas, sundogs, circles about the moon, and the tinting at sunrise and sunset, are produced by the refraction and reflection of the sun's rays by the clouds. The phenomenon known as the "sun's drawing water," consists of the long shadows of broken clouds. Twilight and kindred topics are treated in Astronomy.

† Certain substances are able to split a ray of light into its complementary colors and are said to be *dichroic*. Thus gold-leaf reflects the red and transmits the green.

blue ribbon side by side. The former will take on a yellow and the latter a green tint. Lay a piece of tissue paper upon black letters printed on colored paper. The dark letters will appear of a color complementary to that of the background.*

7. **Interference of Light** (*Newton's Rings*).—Let the convex side of a plano-convex lens be pressed down upon a plane of glass. The two surfaces will apparently touch at the centre. If different circles be described around this point, at all parts of each circle the surfaces will be the same distance apart, and the larger the circle the greater the distance. Now let a beam of red light fall upon the flat surface. A black spot is seen at the centre; around this a circle of red light, then a dark ring, then another circle of red light, and so alternating to the circumference. The distances between the surfaces of the glass, where the successive dark rings appear, are proportional to the numbers 0, 2, 4 . . . . . , and the bright circles to 1, 3, 5 . . . . . This fact suggests the cause. There are two sets of waves, one reflected from the upper surface of the plane glass, and the other from the lower surface of the convex glass. These alternately interfere, producing darkness, and combine, making an intenser color.† To de-

Fig. 164.

* A color is heightened when placed near its complement. A red apple is the brighter for the contrast of the green leaf.—Observe a white cloud through a bit of red glass with one eye and through green glass with the other eye. After some moments, transfer both eyes to the red glass, opening and closing them alternately. The strengthening of the red color in the eye fatigued by its complementary green. is very striking.—In examining ribbons of the same color, the eye becomes wearied and unable to detect the shade, because of the mingling of the complementary hue.

† The play of colors in mother-of-pearl is due to the interference of light in its thin overlapping plates.—In a similar manner the plumage of certain birds reflects changeable hues.—A metallic surface ruled with fine parallel lines not more than $\frac{1}{1000}$ of an inch apart, gleams with brilliant colors.—Thin cracks in plates of glass or quartz, mica when two layers are slightly separated, even the scum floating in stagnant water, breaks up the white light of the sunbeam and reflects the varying tints of the rainbow.—The rich coloring of a soap-bubble is caused by the interference of the rays reflected from the upper and lower surfaces of the bubble.—DIFFRACTION is a kind of interference produced by a beam of light passing along the edge of an opaque body or through a small opening. Ex.: If we hold a fine needle close to one eye and look toward the window, we see several needles.—Place the

termine the length of a wave of red light, we have only to measure the distance between the two glasses at the first ring.

When beams of light of the various colors are used corresponding circles are obtained, having different diameters; red light gives the largest, and violet the smallest. We hence conclude that red waves are the longest, and violet the shortest. The minuteness of these waves passes comprehension. About 40,000 red waves and 60,000 violet ones are comprised within a single inch. Knowing the velocity of light, we can calculate how many of these tiny waves reach our eyes each second. When we look at a violet object, 757 million million of ether-waves break on the retina every moment!

8. Color is analogous to pitch, violet corresponding to the high and red to the low sounds in music. Intensity of color, as of sound, depends on the amplitude of the vibrations. When a body absorbs all the colors of the spectrum except blue, but reflects that to the eye, we call it a blue body; when it absorbs all but green, we call it a green body.* Red glass has the power of absorbing all except the red rays, which it transmits. When a substance *reflects* all the colors to the eye, it seems to us white. If it *absorbs* all the colors, it is black. Thus color is not an inherent property of objects.† In darkness all things are colorless.

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blades of two knives closely together and hold them up to the sky: waving lines of interference will shade the open space.—Look at the sky through the meshes of a veil, or at a lamp-light through a bird-feather or a fine slit in a card, and delicate colors will appear.

* Some eyes are blind to certain colors, as some ears are deaf to certain sounds. "Color-blindness" generally exists as to red. Such a person cannot by the color distinguish ripe cherries from the leaves. Doubtless railway accidents have occurred through this inability to apprehend signals. Dr. Mitchell mentions a naval officer who chose a blue coat and red waistcoat, believing them of the same color; a tailor who mended a black silk waistcoat with a piece of crimson; and another who put a red collar on a blue coat. Dalton could see in the solar spectrum only two colors, blue and yellow, and having once dropped a piece of red sealing-wax in the grass, he could not distinguish it.

† Moisten a swab with alcohol saturated with common salt. On igniting the torch every object will take on a curious ghastly yellow hue from the burning sodium. The gay colors of flowers will instantly be quenched.

9. Polarization of Light (*Double Refraction*).—If we could look at the end of a ray of light as we can at the end of a rod, we should see the particles of ether swimming swiftly to and fro in the direction of all the diameters (Fig. 165). Certain crystals have the power of sifting and arranging these vibrations into two sets at right angles to each other, making a ray of the form seen in Fig. 166. As one set is more refracted than the other, the ray is divided into two—the *ordinary* and the *extraordinary*. Rays which have thus been sifted constitute polarized light. Iceland spar possesses the property of double refraction in a remarkable degree. An object viewed through it appears double. If the crystal be placed on a dot and slowly turned round, two dots will be seen, the second revolving about the first.

FIG. 165.

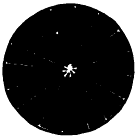
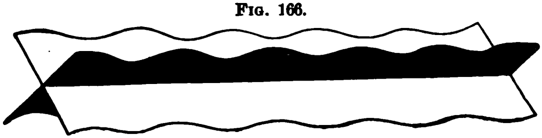


FIG. 166.



Objects seen by polarized light present curious changes. A crystal of quartz reveals beautiful colors due to interference. Looking at a lamp-light through a piece of thin mica, we see a series of polarized rays having a star-like form. When polarized light is passed through common glass no change is noticed, but on slight pressure a system of variegated colors appears. Polarized light therefore affords a delicate means of determining the molecular structure of a body.*

FIG. 167.

* Some substances have the power of twisting the plane of the polarized light. Cane-sugar turns it to the right, and fruit-sugar to the left (*Chemistry*, p. 190). The French government uses a polarizing instrument, in which this principle is applied to test the quality of sugar.

8. OPTICAL INSTRUMENTS.

1. Microscopes (*to see small things*) are of two kinds, *simple* and *compound*. The former consists of one or more convex lenses through which the object is seen directly: the latter contains a simple magnifier for viewing the image of

Fig. 168.

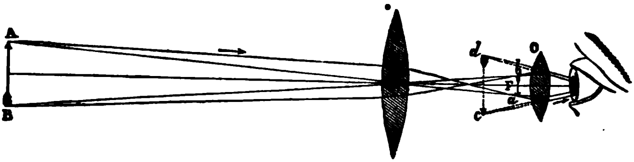
an object produced by a second lens. Fig. 168 represents a compound microscope. At M is a mirror which reflects the rays of light through the object *a*. The object-lens (objective) *o* forms, in the tube above, a magnified, inverted image of the object. The eye-lens O (ocular) magnifies this image.

The magnifying power of the instrument is nearly equal to the product of that of the two lenses. If a microscope increases the apparent diameter of an object 100 times, it is said to have a power of 100 diameters, the surface being magnified $100^2 = 10,000$ times. The eye-piece may be only a single lens, and is really a simple microscope. The object-lens often consists of several lenses, and each one of a combination (p. 161) to prevent aberration.

2. **Telescopes** (*to see afar off*) are of two kinds, *reflecting* and *refracting*. The former contains a large metallic mirror (speculum) which reflects the rays of light to a focus. The observer stands at the side and examines the image with an eye-piece.*

The Refracting Telescope contains an object-lens *o* which forms an image *ab*. This is viewed through the eye-piece O, which produces a magnified, inverted image *cd*. The latter image is as much larger than the former as the focal distance

FIG. 169.

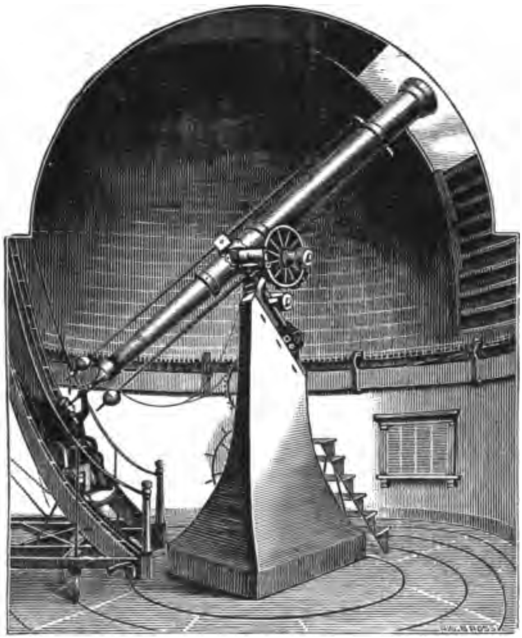


of the eye-piece is less than that of the object-glass. The larger the object-lens the more light is collected with which to view the image. The magnifying power is principally due to the eye-piece.† The apparent inversion of the object is

* The largest reflecting telescope is that of Lord Rosse (See Frontispiece to Astronomy). Its speculum is 6 feet in diameter and gathers about 120,000 times as much light as would ordinarily enter the eye.

† The Washington Observatory telescope has an object-glass 26 inches in diameter, and of excellent defining power. The Chicago telescope has a lens of 18½ inches diameter. It collects "5000 times as much light as the unaided pupil"—equivalent to increasing the astronomer's eye to that size. The use of the telescope depends upon (1st) its light-collecting and (2d) its magnifying power. Thus Herschel, illustrating the former point, says that once he told the time of night from a clock on a steeple invisible on account of the darkness. It is noticeable that while in the compound microscope the image is as much larger than the object as the image is further

FIG. 170.

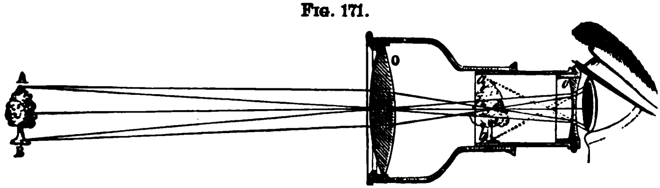


CAMBRIDGE EQUATORIAL.

of no importance for astronomical purposes. In terrestrial observations additional lenses are used to invert the image.

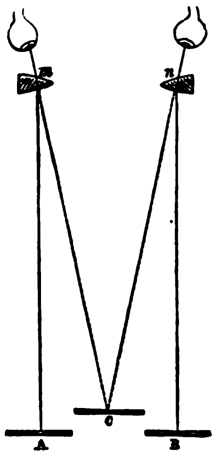
3. The Opera-glass contains an object-glass O and an

FIG. 171.



than the object from the object-glass, in the telescope the image is as much smaller than the object as it is nearer than the object to the object-glass; while in both cases the image is examined with a magnifier. If a power of 1000 be used in looking at the sun, we shall evidently see the sun as if it were only 93,000 miles away, or less than one-half the distance of the moon. The same power used upon the moon would bring that body apparently to within 240 miles of us.

FIG. 172.

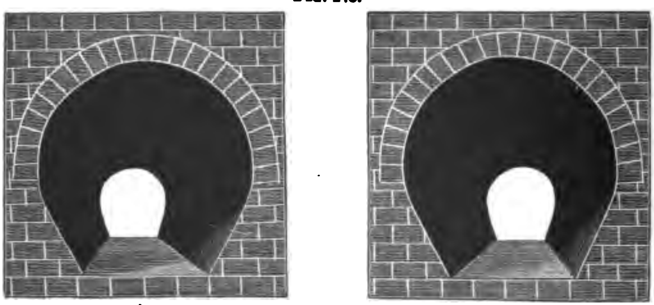


eye-piece *o*. The latter is a double-concave lens; this increases the visual angle by diverging the rays of light, which would otherwise come to a focus beyond the eye-piece. An erect and magnified image is seen at *ab*.

4. **The Stereoscope** contains portions of two convex lenses (Fig. 172). Two photographs A and B are taken by two cameras inclined to each other. This produces two pictures like the views we obtain of an object by the use of each eye alternately. The blending at C causes the appearance of solidity.*

5. **The Magic Lantern**, or Stereopticon, contains a reflector M, which condenses the rays of a light (Fig. 174) upon a lens L. They are there converged upon the object *ab*. Thence a double lens *m* throws a magnified image on the screen AB. *Dissolving views* are produced by two lanterns containing the scenes which are to melt into each other.

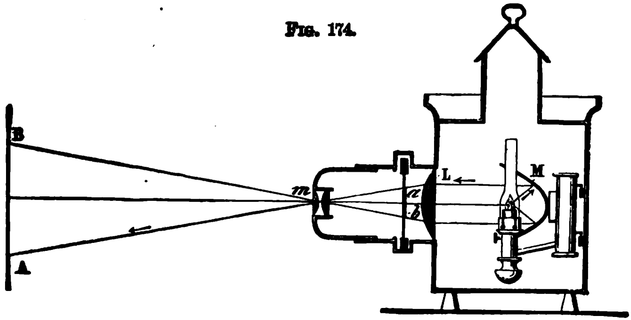
FIG. 173.



A B

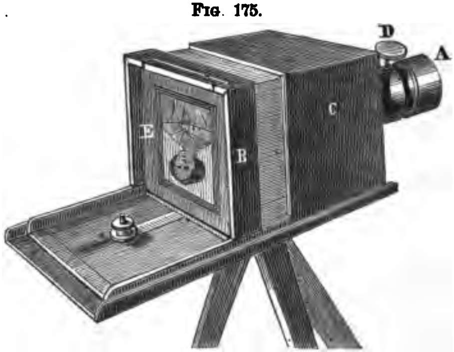
* In Fig. 173 there are two views of a tunnel. In one the opening is at the left of the centre and in the other at the right. If the view be held about 4 inches from the eyes three engravings will be seen, the middle one formed by the mental blending of the other two. By closing either eye alternately one view will disappear.

FIG. 174.



6. The Camera, used by photographers, contains a double-convex lens, A, which throws an inverted image of the object upon the ground-glass screen EB. When the focus has been obtained, the screen is removed and a slide, containing a sensitive film, is inserted in its place. (*Chemistry,* p. 167.)

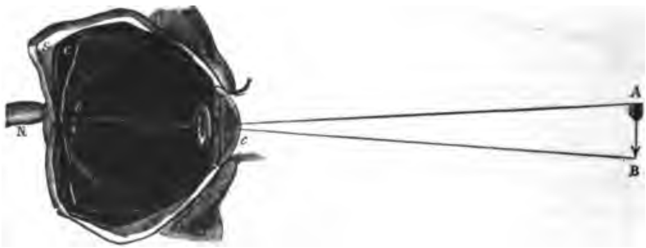
FIG. 175.



7. The Eye is a unique optical instrument resembling a camera. It is rarely, if ever, troubled by spherical or chromatic aberration, and is self-focusing. The outer membrane is termed the *sclerotic* coat, S. It is tough, white, opaque, and firm. A little portion in front, called the *cornea, c,* is more convex and perfectly transparent. The middle or *choroid* coat, C, is soft and delicate, like velvet. It lines the inner part of the eye and is covered with a black pigment, which absorbs the superfluous light. Over it the optic nerve, which enters at the rear, expands in a net-work of delicate fibres termed the

retina, the seat of vision. Back of the cornea is a colored curtain, *hi*, the *iris* (rainbow), in which is a round hole called the *pupil*. The *crystalline lens*, *o*, is a double-convex lens, composed of concentric layers somewhat like an onion, weighing about 4 grains and transparent as glass. Between the cornea and the crystalline lens is a limpid fluid

FIG. 176.



termed the *aqueous humor;* while the *vitreous humor*, a transparent, jelly-like liquid, fills the space back of the crystalline lens.

Let AB represent an object in front of the eye. Rays of light are first refracted by the aqueous humor, next by the crystalline lens, and last by the vitreous humor, forming on the retina an image, *ab*,* which is real, inverted, and smaller than the object. To render vision distinct, the rays must be accurately focused on the retina. If we gaze steadily at an object near by, and then suddenly observe a distant one, we find our vision blurred. In a few moments it becomes clear again, showing that the eye has the power of adapting itself to the varying distances of objects. This is done by a change in the convexity of the crystalline lens.† When

* The diameter of the eye is less than an inch; yet, as we look over an extended landscape, every feature, with all its variety of shade and color, is repeated in miniature on the retina. Millions upon millions of ether waves, converging from every direction, break on that tiny beach, while we, oblivious to the marvellous nature of the act, think only of the beauty of the revelation. Yet in it the physicist sees a new illustration of the simplicity and perfection of the laws and methods of the Divine Workman, and a continued reminder of His forethought and skill.

† Recent investigations seem to show that, instead of the time-honored view of the text, the lens is really turned so as to bring a more or less convex surface in front of the pupil.

the distance at which the clearest vision occurs is less than ten or twelve inches, the person is *near-sighted,* and when greater, *far-sighted.* Too great flatness or convexity of the cornea or crystalline lens will produce this result. The defect, however, often lies in the shape of the eyeball. In far-sightedness the ball is too flat, and the retina too near the lens; in near-sightedness the ball is elongated, so that the retina is too distant. The former can be remedied by convex glasses, which bring the rays to a focus sooner, and the latter by concave, which throw the focus further back.

The retina retains an impression about one-eighth of a second.* This explains why a wheel, when rapidly revolved, appears solid, or a lighted brand like a ring of fire. On the other hand, it requires a moment for an impression to be made. Thus a wheel may be whirled so swiftly that its spokes become invisible.

PRACTICAL QUESTIONS.—1. Why is the secondary bow fainter than the primary? Why are the colors reversed? 2. Why can we not see around the corner of a house, or through a bent tube? 3. What color would a painter use if he wished to represent an opening into a dark cellar? 4. Is white a color? Is black? 5. By holding an object nearer a light, will it increase or diminish the size of the shadow? 6. What must be the size of a glass in order to reflect a full-length image of a person? *Ans.* Half the person's height. 7. Where should we look for a rainbow in the morning? 8. Can two spectators see the same bow? 9. Why, when the drops of water are falling through the air, does the rainbow appear stationary? 10. Why can a cat see in the night? 11. Why cannot an owl see in daylight? 12. Why are we blinded when we pass quickly from a dark into a lighted room? 13. If the light of the sun upon a distant planet is $\frac{1}{100}$ of that which we receive, how does its distance from the sun compare with ours? 14. If, when I sit six feet from a candle, I receive a certain amount of light, how much shall I diminish it if I move back six feet further? 15. Why do drops of rain, in falling, appear like liquid threads? 16. Why does a towel turn darker when wet? 17. Does color exist in the object, or in the mind of the observer? 18. Why is lather opaque, while air and a solution of soap are each transparent? 19. Why does it whiten molasses candy to "pull it"? 20. Why does plastering become lighter in color as it dries? 21. Why does the photographer use a kerosene-oil lamp in the "dark room"? 22. Is the common division of colors into "cold" and "warm" verified in philosophy? 23. Why is the image on the camera, Fig. 175, inverted? 24. Why is the second image seen in a mirror, Fig. 138, brighter than the first? 25. Why does a blow on the head make one "see stars"? *Ans.* The blow excites the optic nerve, and so produces the sensation of light. 26. What is the principle of the kaleidoscope? 27. Which can be seen at

* When one is riding slowly on the cars and looking at the landscape between the upright fence-boards, he catches only glimpses of the view; but *when moving rapidly, these snatches will combine to form a perfect landscape,* which has, however, a grayish tint, owing to the decreased amount of light reflected to the eye.

the greater distance—gray or yellow? 28. Look down into the glass of water shown in Fig. 145, and, at a certain angle, you will see two spoons, one small and having the real handle of the spoon, though apparently bent, and the real spoon with no handle. Explain. 29. When a star is near the horizon, does it seem higher or lower than its true place? 30. Why can we not see a rainbow at midday? 31. What conclusion do we draw from the fact that moonlight shows the same dark lines as sunlight? 32. Why does the bottom of a ship seen under water appear flatter than it really is? 33. Of what shape does a round body appear in water? 34. Why is rough glass translucent while smooth glass is transparent? 35. Why are some bodies brilliant and others dull? 36. Why can a carpenter, by looking along the edge of a board, tell whether it is straight? 37. Why can we not see out of the window after we have lighted the lamp in the evening? 38. Why does a ground-glass globe soften the light? 39. Why can we not see through ground-glass or painted windows? 40. Why does the moon's surface appear flat? 41. Why can we see further with a telescope than with the naked eye? 42. Why is not snow transparent, like ice? 43. Are there rays in the sunbeam which we cannot perceive with the eye? 44. Why, when we press the finger on one eyeball, do we see objects double? 45. Why does a distant light, in the night, seem like a star? 46. Why does a bright light, in the night, seem so much nearer than it is? 47. What color predominates in artificial lights? *Ans.* Yellow. 48. Why does yellow seem white, and blue green, when seen by artificial light? 49. Why are we not sensible of darkness when we wink? 50. Why is the lens of a fish's eye (seen in the eye-socket of a boiled fish) so convex? 51. When do the eyes of a portrait seem to follow a spectator to all parts of a room? 52. Why does the dome of the sky seem flattened? 53. Why do the two parallel tracks of a railroad appear to approach in the distance? 54. Why does a fog magnify objects? 55. If you sit where you cannot see another person's image, why cannot that person see yours? 56. Why can we see the multiple images in a mirror better if we look into it very obliquely? 57. Why is an image seen in water inverted? 58. Why is the sun's light fainter at sunset than at midday? 59. Why can we not see the fence-posts when we are riding rapidly? 60. Ought a red flower to be placed in a bouquet by an orange one? A pink or blue with a violet one? 61. Why are the clouds white while the clear sky is blue? 62. Why does skim-milk look blue and new milk white? 63. What would be the effect of filling the basin, in the experiment shown in Fig. 147, with salt water? 64. Why is not the image of the sun in water at midday so bright as near sunset? 65. Why is the rainbow always opposite the sun?

SUMMARY.

Light comes from the sun and other self-luminous bodies. It is transmitted by means of vibrations in ether, according to the principles of wave-motion. It radiates equally in all directions, travels in straight lines, decreases as the square of the distance, and moves 186,000 miles per second. Light falling upon a body may be absorbed, transmitted or reflected. If the surface be rough, the irregularly-reflected light enables us to see the body; if it be smooth and highly polished, the rays are reflected so nearly as they fall that they form an image of the original object. Surfaces producing such images are

termed mirrors—plane, concave, or convex. The image is seen in the line of the reflected ray, and, in a plane mirror, as far behind the mirror as the object is in front. Multiple images are produced by repeated reflections, as in the kaleidoscope. A concave mirror, as generally used, collects the rays, and serves to magnify an object or to throw a parallel beam of light. A convex mirror scatters the rays, and apparently diminishes the size of an object.

When a ray enters or leaves a transparent body obliquely it is refracted; if passing into a rarer medium it is bent from, and if into a denser, toward a perpendicular. A transparent body with one or more curved surfaces is a lens. There are two classes—convex and concave. The former lens, as generally used, tends, like a concave mirror, to collect the rays of light, and is known as a "magnifier"; the latter, like a convex mirror, scatters the rays of light, and is known as a "diminisher." Mirage is an optical delusion caused by reflection and refraction of light in passing through air composed of strata of unequal density. Owing to the varying refrangibility of the different constituents of the sunbeam, a prism can disperse them into a colored band called the solar spectrum. The spectrum shows white light to consist of seven elementary colors, and that the sunbeam contains, in addition to the luminous rays, heat and chemical rays. By means of the spectroscope we can examine the spectrum of a flame, and find whether it is a burning gas or an incandescent solid. Each substance gives a spectrum with its peculiar lines of color. A gas absorbs the same rays that it is capable of emitting; hence we have absorption spectra, which contain dark instead of colored lines. A delicate mode of analysis is thus furnished, whereby the elements even of the distant stars can be detected. The rainbow is formed by the refraction and reflection of the sunbeam in raindrops. Light, when reflected by or transmitted through bodies, is so modified, chiefly by absorption, as to produce the varied phenomena of color. Each color has its own wave-length, the minuteness of which is almost incredible. Different systems of light, as of sound waves, may coexist. But if any two coincide with similar phases they will strengthen each other; and if with opposite phases, weaken each other. Interference of light, as thus produced, causes the play of colors in the soap-bubble, mother-of-pearl, etc. Polarized light is that in which the molecular vibrations are made in the same plane. It is of use in determining the internal constitution of a body.

The principal optical instruments, including the eye, are adapted to produce and examine the image formed by a lens. In the magic-lantern, stereopticon, and solar microscope, the image is thrown on a screen in a dark room—lamplight being used in the first, the calcium light in the second, and sunlight in the third. In the refracting tele-

scope and the microscope, the image is formed in a tube by a lens at one end and looked at from behind by a lens at the other end. In the eye, which is a small camera-obscura, the image is formed on the retina, whence the sensation is carried by the optic nerve to the brain.

HISTORICAL SKETCH.

The ancients knew that light is propagated in straight lines. They deduced the laws of reflection, and we read that Archimedes set fire to the Roman ships off Syracuse by means of concave mirrors. Euclid and Plato, however, thought that the ray of light proceeds from the eye to the object, an error that was long of correction. One thousand years did not pursue the subject into other departments. The Arabian philosopher, Alhazen, who lived in the eleventh century, discovered the phenomenon shown in Fig. 147. About 1608 the telescope was invented by the Dutch.* Jansen, Metius and Lippersheim each claimed the honor, and the legend is that the discovery grew out of some children at play, accidentally arranging two watch-glasses so as to magnify a distant object. In fact, however, the action of the convex lens was already known, the compound microscope had been invented by Jansen 20 years previously, and the simple microscope was known to the ancient Chaldeans. In 1621 Snell discovered the law of refraction. By its aid Descartes explained the rainbow. Half a century of waiting, and Newton published his investigations in the decomposition of light. He, however, believed in what is known as the "corpuscular theory," which is even yet taught in the older philosophies. This holds that light consists of minute particles of matter radiated in straight lines from a luminous object. In 1676 Roemer, by observing Jupiter's moons (p. 150), found out the velocity of light, which up to that time had been considered instantaneous. A little later, Huygens advanced the undulatory theory, which was applied with singular skill by Young and Fresnel, in the first quarter of the present century, to explain all optical phenomena. (See list of books for additional information, on p. 120.)

* "In 1609, the government of Venice made a considerable present to Signor Galileo, of Florence, Professor of Mathematics at Padua, and increased his annual stipend by 100 crowns, because, with diligent study, he found out a rule and measure by which it is possible to see places 30 miles distant as if they were near, and, on the other hand, near objects to appear much larger than they are before our eyes."—*From an old paper in the Library of Heidelberg University.*

VIII.

ON HEAT.

" *The combustion of a single pound of coal, supposing it to take place in a minute, is equivalent to the work of three hundred horses ; and the force set free in the burning of* 300 *lbs. of coal is equivalent to the work of an able-bodied man for a lifetime.*"

ANALYSIS.

HEAT.

1. PRODUCTION OF HEAT.
   1. Definitions.
   2. Relation between Light and Heat.
   3. Theory of Heat.
   4. Sources of Heat.
   5. Mechanical Equivalent of Heat.
2. PHYSICAL EFFECTS OF HEAT.
   1. Temperature and Specific Heat.
   2. Expansion.
   3. Liquefaction.
   4. Vaporization.
   5. Evaporation.
   6. Spheroidal State.
3. COMMUNICATION OF HEAT.
   1. Conduction.
   2. Convection.
      - (1.) Of Liquids.
      - (2.) Of Gases.
   3. Radiation.
4. STEAM-ENGINE.
   1. Theory of Steam-engine.
   2. Governor.
   3. High-pressure Engine.
5. METEOROLOGY.
   1. General Principles.
   2. Dew.
   3. Fogs.
   4. Clouds.
   5. Rain.
   6. Winds.
   7. Ocean Currents.
   8. Adaptations of Water.

HEAT.

1. PRODUCTION OF HEAT.

1. Definitions.—*Luminous* heat is that which radiates from a luminous body. Ex.: The heat of a white-hot iron. *Obscure* heat is that from a non-luminous source. *Cold* is a relative term, indicating the partial absence of heat. *Gases* and *Vapors* differ but slightly. The former retain their form at the ordinary temperature and pressure. Ex.: Air. The latter are readily condensed and at the ordinary temperature appear as liquids or solids. Ex.: Steam.

2. Relation between Light and Heat.—Thrust a cold iron into the fire. It is at first dark, but soon becomes luminous, like the glowing coals.—Raise the temperature of a platinum wire. We quickly feel the radiation of obscure heat-rays. As the metal begins to glow, our eyes detect a red color, then orange combined with it, and so on through the spectrum. At last all the colors are emitted, and the metal is dazzling white. All bodies become luminous at a fixed temperature. Like light, heat may be reflected, refracted, and polarized. It radiates in straight lines in every direction, and decreases in intensity as the square of the distance. It moves with the same velocity as light. It is therefore believed that light is luminous heat, and that the three classes of waves in the solar spectrum differ merely as one color from another, in the rapidity of the vibrations.*

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* According to Tyndall, 95 per cent. of the rays from a candle are invisible or heat-rays. These may be brought to a focus and bodies fired in the darkness.—Each of the five classes of nerves seems to be adapted to transmit vibrations of its own kind, while it is insensible to the others. Thus, if the rate of oscillation be less than that of red, or more than that of violet, the optic nerve is uninfluenced by the waves. We cannot see with our fingers, taste with our ears, or hear with our nose. Yet these are organs of sensation and sensitive to their peculiar impressions.—"Suppose, by a wild stretch of imagination, some mechanism that will make a rod turn round one of its ends, quite slowly at first, but then faster and faster, till it will revolve any number of times in a second; which is, of course, perfectly imaginable, though you

The longer and slower waves of ether fall upon the nerves of touch, and produce the sensation of heat. The more rapid affect the optic nerve and produce the sensation of light. The shortest and quickest cause chemical changes.

3. Theory of Heat.—Heat is motion. The molecules of a solid are in constant vibration. When we *increase* the rapidity of this oscillation, we heat the body; when we *decrease* it, we cool the body. The vacant spaces between the molecules are filled with ether. As the air moving among the limbs of a tree sets its boughs in motion, and in turn is kept in motion by the waving branches, so the ether puts the molecules in vibration, or is thrown into vibration by them. Ex.: Insert one end of a poker in the fire. The particles in contact with the heat are made to vibrate intensely; the swinging atoms strike their neighbors, and so on, atom by atom, until the oscillation reaches the other end. If we handle the poker, the motion is imparted to the delicate nerves of touch; they carry it to the brain, and pain is felt. In popular language, "the iron is hot," and

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could not find such a rod or put together such a mechanism. Let the whirling go on in a dark room, and suppose a man there knowing nothing of the rod; how will he be affected by it? So long as it turns but a few times in the second, he will not be affected at all unless he is near enough to receive a blow on the skin. But as soon as it begins to spin from sixteen to twenty times a second, a deep growling note will break in upon him through his ear; and as the rate then grows swifter, the tone will go on becoming less and less grave, and soon more and more acute, till it will reach a pitch of shrillness hardly to be borne, when the speed has to be counted by tens of thousands. At length, about the stage of forty thousand revolutions a second, more or less, the shrillness will pass into stillness; silence will again reign as at first, nor any more be broken. The rod might now plunge on in mad fury for a long time without making any difference to the man; but let it suddenly come to whirl some million times a second, and then through intervening space faint rays of heat will begin to steal towards him, setting up a feeling of warmth in his skin; which again will grow more and more intense, as now through tens and hundreds and thousands of millions the rate of revolution is supposed to rise. Why not billions? The heat at first will be only so much the greater. But, lo! about the stage of four hundred billions there is more—a dim red light becomes visible in the gloom; and now, while the rate still mounts up, the heat in its turn dies away, till it vanishes as the sound vanished; but the red light will have passed for the eye into a yellow, a green, a blue, and, last of all, a violet. And to the violet, the revolutions being now about eight hundred billions a second, there will succeed darkness—night, as in the beginning. This darkness too, like the stillness, will never more be broken. Let the rod whirl on as it may, its doings cannot come within the ken of that man's senses."

we are burned. If, without touching it, we hold our hand near the poker, the ether-waves set in motion by the whirling atoms of iron strike against the hand, and produce a less intense sensation of heat. In the former case, the fierce motion is imparted directly; in the latter, the ether acts as a carrier to bring it to us.

4. The Sources of Heat are the sun, stars, and mechanical and chemical forces.

(1.) The molecules of the sun and stars are in rapid vibration. These set in motion waves of ether, which dart across the intervening space, and surging against the earth, give up their motion to it. (2.) Friction and percussion produce heat, because additional motion is thereby imparted to the vibrating particles.* (3.) Chemical action is seen in fire. The oxygen of the air has an affinity for the carbon and hydrogen of the fuel. They rush together. As they strike, their motion is stopped. The shock sets the molecules in vibration. They impart their motion to the ether, and thus start waves of heat.

5. Mechanical Equivalent of Heat (*Joule's Law*).—In these various changes of mechanical-motion into heat-motion no energy is lost. If the heat produced by the blacksmith's hammer falling on the anvil could be gathered up, it would be sufficient to lift the hammer to the point from which it fell. *A pound-weight falling 772 feet, will generate enough heat to raise the temperature of 1 lb. of water 1°;*

* Savages obtain fire by rubbing together two pieces of wood.—A horse hits his shoes against a stone and "strikes fire;" little particles of the metal being torn off are heated by the shock and burn as sparks.—A bullet checked instantly, as by a bone in the body, is partially fused.—A train of cars is stopped by the pressure of the brakes. In a dark night, we see the sparks flying from the wheels, the motion of the train being converted into heat.—A blacksmith pounds a piece of iron until it glows. His strokes set the particles of metal vibrating rapidly enough to send ether-waves of such swiftness as to affect the eye of the observer.—As a cannon-shot strikes an iron target, a sheet of flame pours from it.—Were the earth instantly stopped, enough heat would be produced to "raise a lead ball the size of our globe to 384,000° C." If it were to fall to the sun its impact would produce a thousand times more heat than its burning. The earth thus contains within itself the elements for the fulfillment of the prediction that it shall "melt with fervent heat."

conversely, the amount of heat necessary to elevate the temperature of 1 lb. of water 1°, will raise a pound-weight 772 feet.

2. PHYSICAL EFFECTS OF HEAT.

1. Temperature.—The heat-force increases the kinetic energy (*vis viva*, p. 37) of the molecules and so elevates the temperature of a body. If, however, the same amount of heat be applied to the same weight of different substances they will not show the same increase of temperature. In estimating the *specific heat* (see specific gravity, p. 92) of the various kinds of matter, the quantity of heat required to raise the temperature of 1 lb. of water 1° is taken as the standard. That amount would elevate the temperature of 1 lb. of mercury 30°; hence its specific heat is $\frac{1}{30}$.

2. Expansion.—The heat-force urges the molecules of a body into longer vibrations and so increases its size. Hence the general law "Heat expands and cold contracts." As a rule, gases expand most, liquids next and solids least. The expansive force exerted is often enormous. Thus a rise of 45° C. in the temperature, which may occur during a summer's day, will lengthen a bar of wrought-iron, 10 inches long, $\frac{1}{200}$ of an inch, and if the ends are fastened, exert a strain of 50 tons. When the metal cools, it will contract with the same force.*

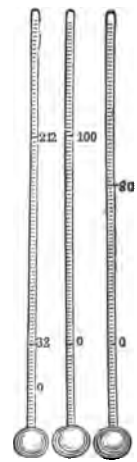
The *Mercurial Thermometer* is an instrument for measuring temperature by the expansion of mercury.† To graduate

* A carriage-tire is put on when hot, that, when cooled, it may bind the wheel together.—Rivets used in fastening the plates of steam-boilers are inserted red-hot. —"The ponderous iron tubes of the Britannia bridge writhe and twist, like a huge serpent, under the varying influence of the solar heat. A span of the tube is depressed only a quarter of an inch by the heaviest train of cars, while the sun lifts it 2¼ inches."—The Bunker-hill monument nods as it follows the sun in its daily course.—Tumblers of thick glass break on the sudden application of heat, because the surface dilates before the motion has time to reach the interior.

† Take the glass tube shown in Fig. 68, and heat the bulb to expel the air. Then plunge the stem in colored water. As the bulb cools, the water will rise and partly fill it. Heat the bulb again until the steam pours out of the stem. On inserting it a second time, the water will fill the bulb. In the manufacture of thermometers, it is customary to have a cup blown at the upper end of the stem. This is filled with mercury, and the air, when expanded, bubbles out through it, while the metal

it, according to Fahrenheit's scale (F.), each thermometer is put in melting ice, and the point to which the mercury sinks is marked 32°, *Freezing-point.** It is then placed in a steam-bath, and the point to which the mercury rises (when the barometric column stands at 30 in.) is marked 212°, *Boiling-point.* The space between these two points is divided into 180°. In the Centigrade scale (C.) the freezing-point is 0, and the boiling-point 100°. In Reaumur's scale (R.), the boiling point is 80°.†

FIG. 177.



3. Liquefaction or fusion. When heat is added to a solid body, a point is finally reached when this repellent force neutralizes the attractive force (p. 43). The molecules then, escaping the grasp of cohesion, move freely on one another. In this process, large quantities of heat are consumed. Thus if ice at 32° be melted, 142° of heat will disappear ‡ and the water will still indicate only 32°. Heat which thus enters a body without raising its temperature, is termed *latent heat.* §

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trickles down as the bulb cools. The mercury is then highly heated, when the tube is melted off and sealed at the end of the column of mercury. The metal contracts on cooling, and leaves a vacuum above.

* The inventor placed zero 32° below the temperature of freezing water, because he thought that absolute cold—a point now estimated to be about −273° C.

† The following formulæ will be of use in comparing the readings of the different scales:

$$R = \tfrac{4}{5}\,C = \tfrac{4}{9}\,(F - 32°). \qquad (1.)$$
$$C = \tfrac{5}{4}\,R = \tfrac{5}{9}\,(F - 32°). \qquad (2.)$$
$$F = \tfrac{9}{5}\,C + 32° = \tfrac{9}{4}\,R + 32°. \qquad (3.)$$
$$1°\,C = 1.8°\,F. \qquad (4.)$$

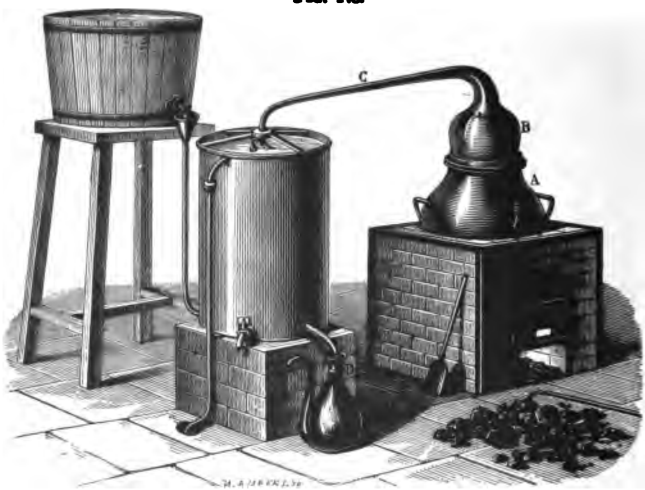
‡ This fact explains why it takes so long a time and so hot a fire to melt snow, and the water when formed is yet ice-cold.

§ It must not be supposed when considering the various changes of solids to liquids, liquids to gases, etc., that the sensible heat which becomes latent is lost. It is occupied in doing work, as in neutralizing the force of cohesion and in overcoming the pressure of the air which opposes expansion. The heat-force thereby becomes a potential energy which can be converted into kinetic. When steam, vapor, gas, and liquids pass back into their former state, their latent heat is restored as sensible. We thus reach the paradoxical conclusion *that thawing is a cooling process and freezing is a warming process.*

Freezing mixtures depend on the principle just explained. In freezing ice-cream, salt and ice are used. Salt having an attraction for water dissolves the ice, and then itself dissolves in the water thus formed. In this process two solids become liquids. The necessary heat is absorbed mainly from the cream.

Liquefaction of gases. When a gas is cooled, the repellent force is weakened, and the molecules once more approach one another. By the continued action of cold and pressure every known gas can be reduced to a liquid form. In the case of carbonic acid, nitrogen, oxygen, etc., the instant the pressure is removed they resume the gaseous state.

FIG. 173.



4. Vaporization.—When heat is applied to a liquid the temperature rises until the boiling-point is reached, when it stops and the liquid is changed to vapor at that constant temperature. The vapor is nearly free from solids dissolved in the liquid. Ex.: Pure or distilled water is obtained by heating water in a boiler A, whence the steam passes

through the pipe C and the *worm* within the condenser S, where it is condensed and drops into the vessel D. The pipe is coiled in a spiral form within the condenser, and is hence termed the worm. The condenser is kept full of cold water from the tub at the left. By carefully regulating the heat, one liquid may be separated from another by distillation. (See *Chemistry*, p. 196.)

Boiling-point. When we heat water, the bubbles which pass off first are the air dissolved in the liquid; next bubbles of steam form on the bottom and sides of the vessel, and, rising a little distance, are condensed by the cold water. Breaking, they produce the sound known as "simmering." As the temperature of the water rises, they ascend higher, until they burst at the surface, and pass off into the air. The violent agitation of the water thus produced is termed boiling.* The boiling-point is not the same in different liquids. This causes the variety in the forms of matter. Some substances vaporize at ordinary temperatures; others melt only at the highest; while the gases of the air are but the steam of substances which vaporize at enormously low temperatures.

The boiling-point of water depends on three circumstances: (1.) *Purity of the water.* A substance dissolved in water ordinarily elevates the boiling-point. Thus salt water boils at a higher temperature than pure water. The air dissolved in water tends by its elastic force to separate the molecules. If this be removed, the boiling-point may

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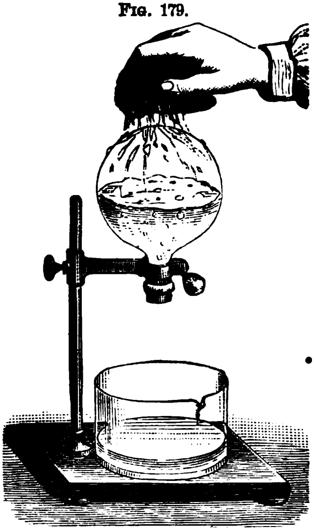
* The temperature of water cannot be raised above the boiling-point, unless the steam be confined. The extra force is occupied in expanding the water into steam. This occupies 1,700 times the space, and is of the same temperature as the water from which it is made. Nearly 1000° of heat become latent in this process, but are made sensible again when the steam is condensed. Water requires more heat to warm it and gives out more heat when it cools (*i. e.*, it has a higher specific heat) than, save one or two unimportant exceptions, any other substance. When ice is at 32° it must absorb 142° before it becomes water at 32°; and when water at 32° it must give off 142° before it solidifies. The heat which boils ice-cold water would raise iron to a glowing red. "The heat-force required to turn a pound of water at 32° into steam would lift a ton weight nearly 400 feet high." Steam is invisible. This we can verify by examining it where it issues from the spout of the tea-kettle. It soon condenses, however, into minute globules, which, floating in the true steam, render the vapor apparently visible.

be elevated over 50°, when the water will be converted into steam with explosive violence.

(2.) *Nature of the vessel.* Water will boil at a lower temperature in iron than in glass. When the surface of the glass is chemically clean, the boiling-point is still higher. This seems to depend on the strength of the adhesion between the water and the containing vessel.

(3.) *Pressure upon the surface* raises the boiling-point.* Water, therefore, boils at a lower temperature on a mountain than in a valley. The temperature of boiling water at Quito is 90° C., and on Mont Blanc 84°. The variation is so uniform that the height of a place can thus be ascertained; an ascent of 596 feet producing a difference of 1° F.

Fig. 179.



The influence of pressure is well illustrated by the following experiment: Boil a glass flask half full of water so as to expel the air. Cork quickly and invert. The pressure of the steam will stop ebullition. A few drops of cold water will condense the steam, and boiling will re-commence. This will soon be checked, but can be restored as before. The process may be repeated until the water cools to blood-heat. The cushion of air which commonly breaks the fall of water is removed, and if the cork be air-tight, the water, when cold, will strike against the flask with a sharp, metallic sound.

* Pressure opposes the repellent heat-force, and so renders it easier for cohesion to hold the particles together. In the interior of the earth there may be masses of matter heated red or white-hot and yet solid, more rigid even than glass, in consequence of their melting-point being raised so high by the tremendous pressure that they cannot liquefy.—*Tait.*

5. Evaporation is a slow formation of vapor, which takes place at ordinary temperatures. Water evaporates even at the freezing-point. Clothes dry in the open air in the coldest weather. The wind quickens the process, because it drives away the moist air near the clothes and supplies dry air. Evaporation is also hastened by an increase of surface and a gentle heat.

Vacuum pans are employed in condensing milk and in the manufacture of sugar. They are so arranged that the air above the liquid in the vessel may be exhausted, and then the evaporation takes place rapidly, and at so low a temperature that burning is avoided.

The cooling effect of evaporation is due to sensible heat becoming latent in the vapor.* Water may be frozen in a vacuum, if the vapor be removed as fast as formed.† Ice is manufactured in the tropics by machines constructed on this principle. The greatest artificial cold known, —220° F., was produced by evaporating in a vacuum liquid nitrous oxide gas and disulphide of carbon.

FIG. 180.

* Pious Mohammedans were formerly accustomed to place, in niches along the public streets, porous earthenware bottles (Fig. 180), filled with water, to refresh the thirsty travellers.

† There is an apparatus for freezing water under the receiver of an air-pump. A watch-glass of water is placed over a pan of strong sulphuric acid, which absorbs the vapor, and, in the vacuum, a part of the water evaporates so rapidly as to freeze the remainder.—Liquid carbonic acid exposed to the open air evaporates so quickly as to convert itself into a snowy-white solid. This will solidify mercury. On throwing the frozen metal into water, the mercury instantly liquefies, but the water turns to ice, the solid thus becoming a liquid and the liquid a solid by the exchange of heat. A cold knife cuts through the mass of frozen mercury as a hot knife would ordinarily through butter. The author, on one occasion, saw Tyndall, during a course of lectures at the Royal Institution at London, when freezing a ladle of mercury in a red-hot crucible, add some ether to hasten the evaporation. The liquid caught fire, but the metal was drawn out from the glowing crucible, through the midst of the flame, frozen into a solid mass.

6. Spheroidal State.—If a few drops of water be put in a hot, bright spoon, they will gather in a globule, which will dart to and fro over the surface. It rests on a cushion of steam, while the currents of air drive it about. If the spoon cool, the water will lose its spheroidal form, and coming into contact with the metal, burst into steam with a slight explosion.*

3. COMMUNICATION OF HEAT.

Heat tends to diffuse itself equally among surrounding bodies.† There are three modes of distribution.

1. Conduction *is the process of heating by the passage of heat from molecule to molecule.* Ex.: Hold one end of a poker in the fire, and the other end soon becomes hot enough to burn the hand. Of the ordinary metals, silver and copper are the best conductors.‡ Wood is a poor conductor, especially "across the grain."

Gases are the poorest conductors; hence porous bodies, as wool, fur, snow, charcoal, etc., which contain large quantities of air, are excellent non-conductors. Refrigerators and ice-houses have double walls, filled between with charcoal, sawdust, or other non-conducting substances. Air is so poor a conductor that persons have gone into ovens, which were so hot as to cook meat, which they carried in and laid on the metal shelves; yet, so long as they did not them-

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* Drops of water spilled on a hot stove illustrate the principle.—By moistening the finger, we can touch a hot flat-iron with impunity. The water assumes this state, and thus protects the flesh from injury.—Furnace-men can dip their moistened hands into molten iron.—Perhaps the historical accounts of persons walking unharmed over red-hot ploughshares are to be explained in this manner.

† If we touch an object colder than we are, it abstracts heat from us, and we say "it feels cold;" if a warmer body, it imparts heat to us, and we say "it feels warm." Adjacent objects have, however, the same temperature, though flannel sheets feel warm, and linen cold. These effects depend upon the relative conducting power of different substances. Iron feels colder than feathers because it robs us faster of our heat.

‡ Place a silver, a German-silver, and an iron spoon in a dish of hot water. Notice how much sooner the handle of the silver spoon is heated than the others.

selves touch any good conductor, they experienced little inconvenience.

Liquids are also poor conductors. Ex.: Hold the upper end of a test-tube of water in the flame of a lamp. The water nearest the blaze will boil without the heat being felt by the hand.

FIG. 181.

2. Convection *is the process of heating by circulation.* (1.) CONVECTION OF LIQUIDS.—Place a little sawdust in a flask of water, and apply heat. We shall soon find that an ascending and a descending current are established. The water near the lamp becoming heated, expands and rises. The cold water above sinks to take its place.

(2.) OF GASES.—By testing with a lighted candle, we shall find at the bottom of a door opening into cold air, a current setting inward, and at the top, one setting outward. The cold air in a room flows to the stove along the floor, is heated, and then rises to the ceiling. Heating by hot-air furnaces depends upon the principle that warm air rises.

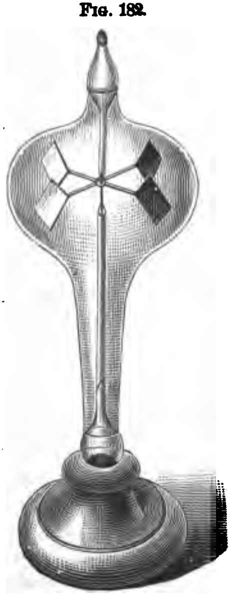
3. Radiation *is the transmission of heat-rays in straight lines.* The heat from the sun comes to the earth in this manner. A hot stove radiates heat. Rays of heat do not always elevate the temperature of the medium through which they pass. When the motion of the ether-waves is stopped, the effect is felt.* Space is not warmed by the sunbeam. Meat can be cooked by radiation, while the air around is at the freezing-point. A rough, unpolished surface is a better radiator than a smooth, bright one. Extent of surface increases radiation. Air, vapor, and glass allow

* The Radiometer is a curious instrument that, for a time, was supposed to exhibit the actual mechanical force of the sunbeam. It consists of a tiny vane

luminous rays of heat to pass through them readily. Thus the heat of the sunbeam easily penetrates our atmosphere, windows, etc. But the earth, and various objects on its surface, absorb and radiate the heat back again as *obscure* heat in long, slow waves. These have no power to pass the watery vapor in the air or through glass. The moisture of the air thus acts as a trap to catch the sunbeam for us. If the aqueous vapor were removed, the earth would become uninhabitable. On the desert of Sahara, where "the soil is fire and the wind is flame," the dry air allows the heat to escape so readily that ice is sometimes formed at night.

Absorption and *reflection* are intimately connected with radiation. A good absorber is also a good radiator, but a good reflector can be neither. Snow is a good reflector, but a poor absorber or radiator. Light colors absorb solar heat less and reflect more than dark colors.* White is generally considered the best reflector, and black the best absorber and radiator.

Fig. 182.



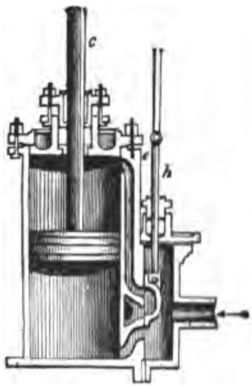
suspended in a glass globe from which the air is exhausted as fully as possible, when the globe is hermetically sealed. The four arms of the vane carry each a thin pith disk, black on one side and white on the other. When daylight falls upon it the vane revolves rapidly. The motion ceases as soon as the light is removed. When different gases are admitted into the globe, the rate of rotation varies. It is now thought that the unequal heating of the black and white surfaces of the disks causes a reaction of the gases, and the force of this reaction varies in accordance with the rapidity of their molecular vibrations.

* Recent experiments show that with artificial heat the molecular condition of the surface varies radiation as well as reflection. In fact, white lead is as good a radiator as lampblack.—On one side of a sheet of paper paste letters of gold-leaf. Spread over the opposite side a thin coating of scarlet iodide of mercury—a salt which turns yellow on the application of heat. (See *Chemistry*, p. 261.) Turn the scarlet side down. Hold over the paper a red-hot iron. The gold-leaf will reflect the heat, but the paper spaces between the letters will absorb it, and on turning the paper over, the gilt letters will be found traced in scarlet on a yellow background.

4. THE STEAM-ENGINE.

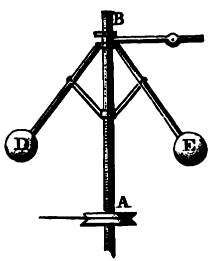
When steam rises from water at a temperature of 212° it has an elastic force of 15 lbs. per square inch. If the steam be confined and the temperature raised, the elastic force will be rapidly increased.

FIG. 183.



1. The Steam-engine is a machine for using the elastic force of steam as a motive power. There are two classes, *high-pressure* and *low-pressure.* In the former, the steam, after it has done its work, is forced out into the air; in the latter, it is condensed in a separate chamber by a spray of cold water.* The figure represents the piston and connecting pipes of an engine. The steam from the boiler passes through the pipe into the steam-chest, as indicated by the arrow. The sliding-valve worked by the rod *h* lets the steam into the cylinder, alternately above and below the piston, which is thus made to play up and down by the expansive force.

FIG. 184.

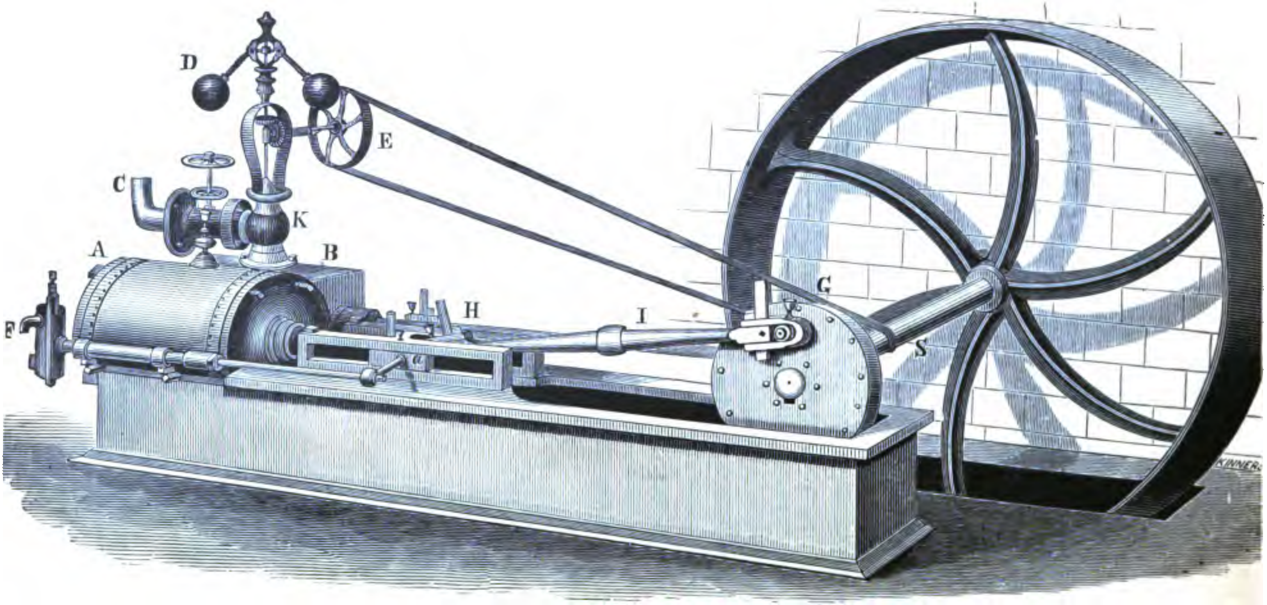


2. The Governor is an apparatus for regulating the supply of steam. AB is the axis around which the heavy balls E and D revolve. When the machine is going too fast the balls fly out and shut off a portion of the steam; when too slowly, they fall back, and, opening the valve, let on the steam again.

3. A High-pressure Engine is

* As the steam is condensed in the low-pressure engine, a vacuum is formed behind the piston; while the piston of the high-pressure engine acts against the pressure of the air. The elastic force of the steam must be 15 lbs. per square inch greater in the latter case.

Fig. 185.



High-Pressure Steam Engine.

shown in Fig. 185. A represents the cylinder, B the steam-chest, C the throttle-valve in the pipe through which steam is admitted from the boiler, D the governor, E the band-wheel by which the governor is driven, F the pump, G the crank, I the conductor attached to *a* the cross-head, H the eccentric rod (*h* in Fig. 183) which works the sliding-valve in the steam-chest, K the governor-valve, S the shaft by which the power is conveyed to the machinery. The cross-head, *a,* slides to and fro in a groove, and is fastened to the rod which works the piston in the cylinder A. The expansive force of the steam is thus communicated to *a,* thence to I, by which the crank is turned. The heavy fly-wheel renders the motion uniform (p. 78).

5. METEOROLOGY.

1. General Principles.—(1.) The air always contains moisture. The amount it can receive depends upon the temperature; warm air absorbing more, and cold air less. At 75°, a cubic yard of air can hold over half an ounce of water; a reduction of 27° will cause half that quantity to be deposited. When the air at any temperature contains all the vapor it can hold, it is said to be saturated; *any fall of temperature will then condense a part of the vapor.*

(2.) When air expands against pressure (*i. e.,* doing work in the expansion) its sensible heat becomes latent, and there is a fall of its temperature. The warm air from the earth ascending into the upper regions, is thus rarefied and cooled. Its vapor is then condensed into clouds, and often falls as rain. Owing to this expansion of the atmosphere and the greater radiation of heat in the dry air of the upper regions, there is a gradual diminution of the temperature as the altitude increases, the mean rate in the north temperate zone being about 1° for 300 feet.

2. Dew.*—The grass at night, becoming cooled by radi-

* Dew was anciently thought to possess wonderful properties. Baths in this precious liquid were said greatly to conduce to beauty. It was collected for this purpose, and for the use of the alchemists in their weird experiments, by spreading

ation, condenses upon its surface the vapor of the air. Dew will gather most freely upon the best radiators, as they will the soonest become cool. Thus grass, leaves, etc., which need the most, get the most. It will not form on windy nights, because the air is constantly changing and does not become cool enough to deposit its moisture. In tropical regions the nocturnal radiation is often so great as to form ice. In Bengal, water is exposed for this purpose in shallow earthen dishes resting on rice straw. The most dew collects on a clear, cloudless night. In Chili, Arabia, etc., by its abundance, it supplies the place of rain. When the temperature of plants falls below 32°, the vapor is frozen upon them directly, and is called *white* or *hoar-frost.*

3. Fogs are formed when the temperature of the air falls below the *dew-point, i. e.,* the temperature at which dew is deposited. They are characteristic of low lands, rivers, etc., where the air is saturated with moisture.

4. Clouds differ from fogs only in their elevation in the atmosphere. They are formed when a warm, humid wind penetrates a cold air, or a cold wind a warm, humid air. Clouds are constantly falling by their weight, but as they melt in the warm air below, by condensation they increase above.

The *nimbus* cloud is a dark-colored cloud from which rain is falling.

The *stratus* cloud is composed of broad, widely-extended cloud-belts, sometimes spread over the whole sky. It is the lowest cloud, and often rests on the earth, where it forms a fog. It is the night-cloud.

The *cumulus* cloud is made up of large cloud-masses looking like snow-capped mountains piled up along the horizon. It forms the summits of pillars of vapor, which, streaming up from the earth, are condensed in the upper air. It is

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fleeces of wool upon the ground. Laurens, a philosopher of the middle ages, claimed that dew is ethereal, so that if we should fill a lark's egg with it and lay it out in the sun, immediately on the rising of that luminary, the egg would fly off into the air!

the day-cloud. When of small size and seen near mid-day, it is a sign of fair weather.

The *cirrus* (curl) cloud consists of light, fleecy clouds floating high in air. It is composed of spiculæ of ice or flakes of snow.

FIG. 186.

Different kinds of clouds—1 bird indicates the nimbus, 2 birds the stratus, 3 birds the cumulus, and 4 birds the cirrus cloud.

The *cirro-cumulus* is formed by small rounded portions of cirrus cloud, having a clear sky between. Sailors call this a "mackerel sky." It accompanies warm, dry weather.

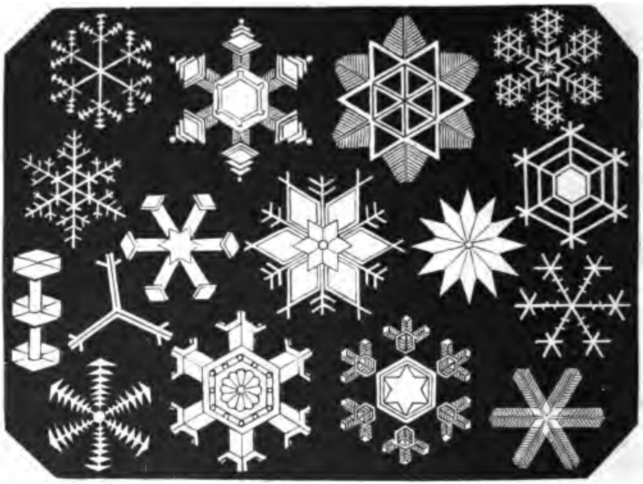
The *cirro-stratus* is produced when the cirrus cloud spreads into long, slender strata. It forebodes storms.

The *cumulo-stratus* presents the peculiar form called "thunder-head." It is caused by a blending of the cumulus with the stratus, and is a precursor of thunder-storms.

5. Rain is vapor condensed by the sudden cooling of the air in the upper regions. At a low temperature the vapor is frozen directly into *snow*. This may melt before it reaches

the earth, and fall as rain. A sudden draught of cold air into a heated ball-room has produced a miniature snow-storm. The wonderful variety and beauty of snow-crystals are illustrated in the figure.

Fig. 187.



6. Winds are produced by variations in the temperature of the air. The atmosphere at some point is expanded, rises, and colder air flows in to supply its place. This produces currents. The *land and sea breezes* of tropical islands are caused by the unequal specific heat of land and water. During the day the land becomes more highly heated than the water, and hence toward evening a sea-breeze sets in from the ocean. At night the land cools faster than the water, and so toward morning a land-breeze sets out from the land.

Trade-winds are so named because by their regularity they favor commerce. A vessel on the Atlantic Ocean will sometimes, without shifting a sail, set steadily before this wind from Cape Verde to the American coast. The air about the equator is highly heated, and, rising to the upper

regions, flows off north and south. The cold air near the poles sets toward the equator to fill its place. If the earth were at rest this would make an upper warm current flowing from the equator, and a lower cold current flowing toward it. As the earth is revolving on its axis from west to east, the under current starting from the poles is constantly coming to a part moving faster than itself. It therefore lags behind. When it reaches the north equatorial regions it lags so much that it becomes a current from the northeast, and in the south equatorial regions a current from the southeast.

7. Ocean Currents are produced in a similar manner. The water heated by the vertical sun of the tropics rises and flows toward the poles. The Gulf Stream, which issues from the Gulf of Mexico, carries the heat of the Caribbean Sea across the Northern Atlantic to the shores of Scotland and Norway. This tropical river flowing steadily through the cold water of the ocean, rescues England from the snows of Labrador. Should it by any chance break through the Isthmus of Panama, Great Britain would be condemned to arctic glaciers.

8. Adaptations of Water.—The great specific heat of water exercises a marked influence on climate. Warm winds sweeping northward meet the colder air of the temperate regions and deposit their moisture. The latent heat which the vapor absorbed in the sunny South is set free, to temper the severity of our snowy climate. Thus, aërial and oceanic currents constitute a water circulation which is a natural steam-apparatus on the grandest scale, having a boiler at the equator and steam-pipes running over the globe. Water also tends to prevent sudden changes of weather. In the summer it absorbs vast quantities of heat, which it gives off in the fall to moderate the approach of winter. In the spring the melting ice and snow drink in the warmth of the sunbeam, which else might prematurely coax forth the tender buds. Since so much heat is required to melt the ice and snow, they dissolve very slowly, and thus

ward off the disastrous floods which would follow, if they passed quickly into the liquid state.

Water contains air, which is necessary for the support of fish. Just here occurs one of those happy coincidences which frequently startle the reverent searcher in Nature. Were water deprived of air, it would be liable to explode at any moment when it happened to be heated above 212°. Every stove-boiler would need a thermometer. A tea-kettle would require as careful watching as a steam-engine, and our kitchens would witness frequent and perhaps disastrous explosions.

Water, like other liquids, expands with heat, and contracts, on cooling, down to 39° F.* Then it slowly expands until it reaches 32° F., when it freezes.† The bursting of water-pipes and pails is a familiar example of this exception. Under the operation of the general law, the water at the surface radiating its heat and becoming chilled, would contract and fall to the bottom, while the warm water below would rise to the top. This process would continue until the freezing-point was reached, when the whole mass would solidify into ice. Our lakes and rivers would freeze solid every winter. This would be fatal to the fish. In the spring, the ice would not, as now, buoyant and light, float and melt in the direct sunbeam, but, lying at the bottom, would be protected by the non-conducting water above. The longest summer would not be sufficient to thaw the deeper bodies of water. An exception prevents these calam-

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* Since ice when it melts contracts, pressure aids in liquefaction and so lowers the melting-point (p. 190). A glacier descending a mountain melts at every place where there is pressure and freezes again when the obstacle is passed. Bits of ice when squeezed freeze together. This property is called *regelation*. In the winter, snow is packed into ice by loaded wagons.

† Fit a small flask with a cork, through which passes an upright glass tube. Fill with colored water. Apply heat to the flask until the liquid runs over the top of the tube. This shows the expansion by heat. Now apply a freezing mixture to the flask, and at first the liquid in the tube falls, but soon begins to rise. When it runs over as before, apply heat and it shrinks back again. Thus *cold will expand and heat contract it.* When water is at its maximum density (about 39°) expansion sets in alike, whether you heat or cool it.

itous consequences.* The cold water expanding and rising to the top protects the warm water beneath, while ice itself, being a non-conductor, preserves the temperature during the winter.

Water,† in freezing, has a tendency to free itself from impurities. Thus, melting ice furnishes a means of obtaining fresh water in Arctic regions. If a barrel of vinegar freeze, we shall find the acid collected in a little mass at the centre of the ice.

When the dew gathers at night sufficiently to form a covering upon the plants, being a non-conductor, it stops farther radiation of heat. Thus, by a nice provision, the effect of radiation checks the radiation itself, as soon as the wants of the thirsty vegetation are supplied.

PRACTICAL QUESTIONS.—1. Why will one's hand, on a frosty morning, freeze to a metallic door-knob sooner than to one of porcelain? 2. Why does a piece of bread toasting curl up on the side exposed to the fire? 3. Why do double windows protect from the cold? 4. Why do furnace-men wear flannel shirts in summer to keep cool, and in winter to keep warm? 5. Why do we blow our hands to make them warm, and our soup to make it cool? 6. Why does snow protect the grass in winter? 7. Why does water "boil away" more rapidly on some days than on others? 8. What causes the crackling sound of a stove when a fire is lighted? 9. Why is the tone of a piano higher in a cold room than in a warm one? 10. Ought an inkstand to have a large or a small mouth? 11. Why is there a space left between the ends of the rails on a railroad track? 12. Why is a person liable to take cold when his clothes are damp? 13. What is the theory of corn-popping? 14. Could vacuum-pans be employed in cooking? 15. Why does the air feel so chilly in the spring, when snow and ice are melting? 16. Why, in freezing ice-cream, do we put the ice in a wooden vessel and the cream in a tin one? 17. Why does the temperature generally moderate when snow falls? 18. What causes the singing of a tea-kettle? *Ans.* The escaping steam is thrown into vibration by the shape of the spout. 19. Why does sprinkling a floor with water cool the air? 20. How low a degree of tem-

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* Certain metals—iron, bismuth, etc.—are also exceptions to the general law. This fact adapts them for castings. Who shall say these are not all thoughtful provisions for our wants?

† Water distills from the ocean and land as vapor, at one time cooling and refreshing the air, at another moderating its wintry rigor. It condenses into clouds, which shield the earth from the direct rays of the sun, and protect against excessive radiation. It falls as rain, cleansing the air and quickening vegetation with renewed life. It descends as snow, and, like a coverlet, wraps the grass and tender buds in its protecting embrace. It bubbles up in springs, invigorating us with cooling, healing draughts in the sickly heat of summer. It purifies our system, dissolves our food, and keeps our joints supple. It flows to the ocean, fertilizing the soil, and floating the products of industry and toil to the markets of the world. (See *Chemistry*, pp. 56-63.)

perature can be marked by a mercurial thermometer? 21. If the temperature is 70°F., what is it C.? 22. Will dew form on an iron bridge? On a plank walk? 23. Why will not corn pop when very dry? 24. When the interior of the earth is so hot, why do we get the coldest water from a deep well? 25. Ought the bottom of a tea-kettle to be polished? 26. Which boils the sooner, milk or water? 27. Is it economy to keep our stoves highly polished? 28. If a thermometer be held in a running stream, will it indicate the same temperature that it would in a pailful of the same water? 29. Which makes the better "holder," woollen or cotton? 30. Which will give out the more heat, a plain stove or one with ornamental designs? 31. Does dew fall? 32. What causes the "sweating" of a pitcher? 33. Why is evaporation hastened in a vacuum? 34. Does stirring the ground around plants aid in the deposition of dew? 35. Why does the snow at the foot of a tree melt sooner than that in the open field? 36. Why is the opening in a chimney made to decrease in size from bottom to top? 37. Will tea keep hot longer in a bright or a dull teapot? 38. What causes the snapping of wood when laid on the fire? *Ans.* The expansion of the air in the cells of the wood. 39. Why is one's breath visible on a cold day? 40. What gives the blue color to air? *Ans.* The opaque particles floating in it reflect the blue light of the sunbeam. 41. Why is light-colored clothing cooler in summer and warmer in winter than dark? 42. How does the heat at two feet from the fire compare with that at four feet? 43. Why does the frost remain later in the morning upon some objects than upon others? 44. Is it economy to use green wood? 45. Why does not green wood snap? 46. Why will a piece of metal dropped into a glass or porcelain dish of boiling water increase the ebullition? 47. Which can be ignited the more quickly with a burning-glass, black or white paper? 48. Why does the air feel colder on a windy day? 49. In what did the miracle of Gideon's fleece consist? 50. Could a burning-lens be made of ice? 51. Why is an iceberg frequently enveloped by a fog? 52. Would dew gather more freely on a rusty stove than on a bright kettle? 53. Why is a clear night colder than a cloudy one? 54. Why is no dew formed on cloudy nights? 55. Why will "fanning" cool the face? 56. How are safes made fire-proof? 57. Why can you heat water quicker in a tin than a china cup? 58. Why will a woollen blanket keep ice from melting? 59. Does dew form under trees? 60. What is the principle of heating by steam? 61. Why is a gun firing blank cartridges more heated than one firing balls? 62. What is the cause of "cloud-capped" mountains? 63. Show how the glass in a hot-house acts as a trap to catch the sunbeam. 64. Does the heat of the sun come in through our windows? 65. Does the heat of our stoves pass out in the same way? 66. Is a heavy dew a sign of rain? *Ans.* Yes; because it shows that the moisture of the air is easily condensed. 67. Is a dusty boot hotter to the foot than a polished one? 68. The top of a mountain is nearer the sun, why is it not warmer? 69. What is hoar-frost? *Ans.* Frozen dew. 70. Why will a slight covering protect plants from frost? *Ans.* Because it prevents radiation. 71. Why is there no frost on cloudy nights? *Ans.* The clouds act like a blanket, to prevent radiation and keep the earth warm. 72. Can we find frost on the windows and on the stone-flagging the same morning? 73. Why will not snow "pack" into balls except in mild weather? 74. Why is the sheet of zinc under a stove so apt to become puckered? 75. Why does a mist gather in the receiver of the air-pump as the air becomes rarefied? 76. Why are the tops of high mountains in the tropics covered with perpetual snow?

SUMMARY.

Heat is produced by longer and less refrangible waves and slower vibrations of ether than those which cause light. Both luminous and obscure heat may be radiated, reflected, refracted, absorbed, focused, and polarized in precisely the same manner as the light-force. In fact, light is only visible radiant heat. If we elevate the temperature of a body sufficiently, we can change heat-rays into light-rays. A body which allows the radiant heat to pass through it easily is styled *diathermanous;* rock-salt is such a body, being to heat-rays what glass is to light-rays. The sun is the principal source of heat. But heat can be obtained by chemical and mechanical means. In burning coal we secure it by the former method. Mechanical force may be changed directly into heat, as in striking fire with flint and steel, and in hammering a bullet on an anvil until it is hot. According to Joule's law, 772 feet fall of a weight corresponds to 1° of temperature in the same amount of water. (Recent investigations by Joule and others indicate that 780 feet is nearer the exact truth.)

Among the physical effects of heat are a change of temperature, expansion, liquefaction, vaporization, and evaporation. The heat-force increases the *vis viva* of the molecules, thus elevating the temperature; and the increased vibration of the molecules causes an expansion of the body. The latter is so uniform that it is used to indicate changes of temperature, as in the thermometer. The expansion of the metals by heat is turned to account in many art processes. The walls of a gallery in the Conservatoire des Arts et Métiers in Paris, had begun to bulge. To remedy this, iron rods were passed across the building and screwed into plates on the outside of the walls. By heating the bars, they were expanded, when they were screwed up tightly. Being then allowed to cool they contracted, thus drawing the walls back toward a perpendicular.

Heat is the great antagonist of cohesion. The liquid and gaseous states of bodies depend on its relative presence or absence (absolute cold is as yet only a theoretical condition, all bodies with which we are familiar containing heat). When the heat force nearly balances the cohesive, the body breaks down into a liquid, and when the repel lent fairly triumphs, the particles fly off as a gas. Immediately before and after each of these marked changes, viz.: of a solid to a liquid and of a liquid to a gas, the thermometer indicates the same temperature. Thus water from melting ice affects the thermometer just as the ice does, and steam is no hotter than the boiling water. The heat

which, in these processes, becomes hidden from the thermometer is called latent, though we now know that, being occupied in doing internal work, it has merely taken the static form, and can be readily turned again into the dynamic. The so-called latent heat of water is only the potential heat-energy of the separated molecules, which will reappear the instant the molecules collapse and come once more within the grasp of cohesion. On this principle is based the method of heating by steam. Evaporation is a slow vaporization that takes place at all temperatures, but may be greatly increased by a diminution of pressure, as in a vacuum. It is a cooling process, and is practically applied to the manufacture of ice.

By the subtraction of heat, *i. e.*, by cold, and by the addition of pressure, which antagonizes the repellent heat-force, gases may be liquefied and even congealed, the transparent carbonic-acid gas thus becoming a snowy solid. What were formerly called the "permanent gases" (oxygen, hydrogen, etc.), have recently (Dec. 1877) been liquefied by means of the cold produced by their rarefaction (see p. 197) when they were suddenly released from a pressure of two or three hundred atmospheres.

Heat is *conducted* from molecule to molecule of a body, *radiated* in straight lines through air (or space), and *circulated* by the transference of heated masses through a change of specific gravity due to expansion. The first method is characteristic of solids, and the third of liquids and gases. The elastic force of steam increases when it is confined and a higher temperature is reached. The steam-engine utilizes this principle. There are two forms of this machine, the high-pressure and the low-pressure, according as the waste steam is ejected into the air or condensed in a separate chamber. The phenomena of dew, rain, etc. depend upon the fact that a change from a higher to a lower temperature causes the air to deposit its moisture.

HISTORICAL SKETCH.

Democritus, the originator of the Atomic Theory, held that heat consists of minute spherical particles radiated rapidly enough to penetrate every substance. Until very recently heat and light were thus reckoned among the Imponderables, *i. e.*, matter which has no weight. Still, even in early times, some philosophers caught glimpses of a true theory. Aristotle considered heat more a condition than a substance. Bacon, in his Novum Organum, wrote: "Heat is a motion of expansion;" and elsewhere, "Essential heat is motion and nothing else." Locke, half a century later, said: "Heat is a very brisk agitation of

the insensible parts of an object, which produces in us the sensation from whence we denominate the object hot, so that what in our sensation is heat, in the object is motion."

The material view, however, held its ground. At the beginning of the 18th century, Stahl elaborated a theory that a buoyant substance called *phlogiston* is the principle of heat, and that when a body burns, its phlogiston escapes as fire. In 1760, Dr. Black investigated and made known the principles of what he termed *latent* heat, *i. e.*, heat which becomes hidden when ice is turned into water or water into steam. Priestley discovered, in 1774, and Lavoisier afterward developed, the modern view of combustion. But the latter philosopher then advanced the theory that heat (caloric) is an actual substance, which passes freely from one body to another and combines at pleasure. This caloric theory still holds its place in our older philosophies. Toward the close of the 18th century, Benjamin Thompson, better known as Count Rumford, a native of Woburn, Mass., but in the employ of the Elector of Bavaria, proved the convertibility of force. "He first took the subject," as Prof. Youmans well remarks, "out of the domain of metaphysics, where it had been speculated upon since the time of Aristotle, and placed it on the true basis of physical experiment."

Rumford was led to investigate the nature of heat from noticing, in the workshops at Munich, how hot the cannon became while boring. There seemed to be no limit to the amount of heat which could be produced, yet the cannon, the borer and the chips lost nothing, so far as he could detect. If heat were a fluid, as the caloric theory asserted, then there should be an end to the process, sooner or later. Rumford now began to get gleams of the truth of the vibratory theory. Taking a large piece of brass with a hollow at one end, he fitted to it a blunt steel borer, which pressed down upon the metal with a weight of 10,000 lbs. This apparatus he placed in a box holding about 18¾ lbs. of water. The brass was then made to revolve by horse-power at the rate of 32 times per minute In the beginning the water in the box was at 60° F., but in two hours and a half it actually boiled. "It would be difficult," wrote Rumford, "to describe the surprise and astonishment of the bystanders to see so large a quantity of water heated and actually made to boil without any fire." He naively adds that he was himself as delighted as a child, and forgot all the dignity becoming a philosopher. By this experiment he had proved that *motion can be turned into heat.* His experiments, however, conclusive as they now seem to be, were, at the time, the subject of ridicule. Sir Humphrey Davy next began to see the truth, and, in 1799, melted two pieces of ice by friction in a vacuum.

Soon the scientific world seemed to be ripe for this discovery, and it appears to have sprung up spontaneously in men's thoughts every-

where. Mayer, a physician of Germany, and Grove, of England, proved the mutual relation of the forces, the latter first using the term "Correlation of Forces," since changed to Conservation of Energy. Joule discovered the law of the "Mechanical Equivalent of Heat," about 1843. In his famous experiments he used pound-weights made to fall through a measured distance. Cords were attached to them, so that, as they fell, they turned a paddle-wheel placed in a box of water. Other liquids were used instead of the water. The rise of temperature in the liquids was carefully marked. The loss by friction in the apparatus was estimated, and so, at last, the dynamical theory of heat was fully demonstrated. Names of philosophers well known to us, such as Henry, Helmholtz, Faraday, Thomson, Maxwell, Leconte, Youmans, Stewart, and Tyndall, are associated with the final establishment of this theory.

Consult, on this interesting subject, Tait's "Recent Advances in Physical Science;" Stewart's "Treatise on Heat;" Tyndall's "Heat a Mode of Motion;" Maxwell's "Theory of Heat;" Thurston's "History of the Growth of the Steam-Engine;" Buckley's "Short History of Natural Science;" Smiles's "Lives of Boulton and Watt;" Youmans's "Correlation of the Physical Forces;" "Read and the Steam-engine;" American Cyclopædia, Art. "Steam-engine;" Popular Science Monthly, Vol. XII, p. 616, Art. "Liquefaction of Gases;" Loomis's "Meteorology," and Maury's "Physical Geography of the Sea."

IX.

ON ELECTRICITY.

" That power which, like a potent spirit, guides
The sea-wide wanderers over distant tides,
Inspiring confidence where'er they roam,
By indicating still the pathway home;—
Through nature, quickened by the solar beam,
Invests each atom with a force supreme,
Directs the cavern'd crystal in its birth,
And frames the mightiest mountains of the earth;
Each leaf and flower by its strong law restrains,
And binds the monarch Man within its mystic chains."

HUNT.

ANALYSIS.

ELECTRICITY.

- **1. MAGNETIC ELECTRICITY.**
  - 1. MAGNETS.
    - (1.) Different kinds of.
    - (2.) The poles.
    - (3.) Magnetic curves.
    - (4.) Magnetic needle.
    - (5.) Attraction and repulsion.
  - 2. INDUCTION.
  - 3. TO MAKE A MAGNET.
  - 4. THE COMPASS.
  - 5. POLARITY OF THE NEEDLE.
    - (1.) Why the needle points north and south.
    - (2.) Dipping needle.
  - 6. MAGNETISM OF THE EARTH.
- **2. FRICTIONAL ELECTRICITY.**
  - 1. ELECTROSCOPE.
  - 2. TWO KINDS OF ELECTRICITY.
  - 3. THEORY OF ELECTRICITY.
  - 4. CONDUCTORS AND INSULATORS.
  - 5. ELECTRICAL MACHINE.
  - 6. INDUCTION.
    - (1.) Definition and illustration.
    - (2.) Faraday's theory.
  - 7. ATTRACTION AND REPULSION.
    - (1.) Electric chimes.
    - (2.) Dancing image.
  - 8. LEYDEN JAR.
  - 9. ELECTRICITY RESIDES ON THE SURFACE.
  - 10. EFFECT OF POINTS.
  - 11. LIGHTNING.
    - (1.) Definitions.
    - (2.) Aurora Borealis.
    - (3.) Lightning-rods.
  - 12. VELOCITY OF ELECTRICITY.
  - 13. EFFECTS OF ELECTRICITY.
    - (1.) Physical.
    - (2.) Chemical.
    - (3.) Physiological.
- **3. GALVANIC ELECTRICITY.**
  - 1. SIMPLE GALVANIC CIRCUIT.
  - 2. SOURCE OF THE HYDROGEN.
  - 3. GALVANIC CURRENT.
  - 4. ELECTRICAL POTENTIAL.
  - 5. BATTERIES.
  - 6. QUANTITY AND INTENSITY.
  - 7. COMPARISON OF FRIC. WITH GALVANIC ELEC.
  - 8. EFFECTS OF GALVANIC ELECTRICITY.
    - (1.) Physical.
    - (2.) Chemical.
    - (3.) Physiological.
- **4. ELECTRO-MAGNETISM.**
  - 1. INFLUENCE OF A CURRENT ON A NEEDLE.
  - 2. GALVANOMETER.
  - 3. ELECTRO-MAGNETS.
  - 4. MOTION PRODUCED BY ELECTRICITY.
  - 5. MAGNETO-ELECTRICITY.
  - 6. INDUCED CURRENTS.
  - 7. THE TELEPHONE.
  - 8. THE MICROPHONE.
- **5. THERMAL ELECTRICITY.**
- **6. ANIMAL ELECTRICITY.**

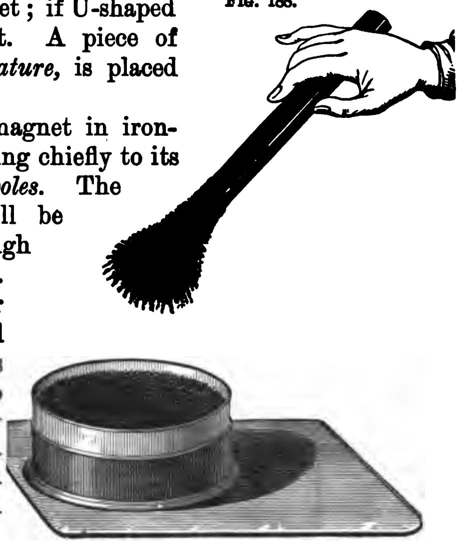
ELECTRICITY.

The electrical force manifests itself in several different forms, Magnetic, Frictional, Galvanic, Thermal and Animal Electricity. These are intimately connected; their laws are strikingly related; they produce many effects in common; and one can give rise to another.

1. MAGNETIC ELECTRICITY.

1. Magnets.*—A natural magnet is an ore of iron (Fe_3O_4, *Chemistry*, p. 154), generally known as the loadstone (Saxon, lædan, to lead). The artificial *magnet* is a magnetized steel bar; if straight, it is called a *bar* magnet; if U-shaped a *horse-shoe* magnet. A piece of soft iron, the *armature*, is placed on the end.

Fig. 188.



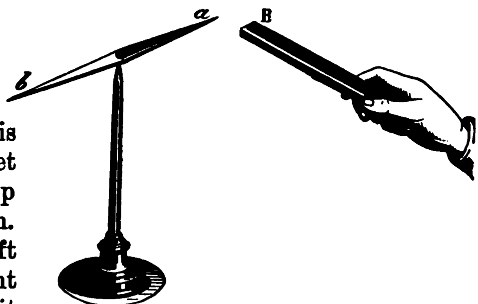
If we insert a magnet in iron-filings, they will cling chiefly to its ends termed the *poles.* The magnetic force will be exerted even through an intervening body. Lay a sheet of paper on a magnet and sprinkle iron-filings upon it. Gently tap the paper and they will collect in curious lines, the *magnetic curves,* radiating from the poles. If a small bar magnet be suspended so as to swing freely in

* The term is derived from the fact that an ore of iron possessing this property was first found at Magnesia, in Asia Minor.

a horizontal plane, one pole will point toward the north and the other toward the south. The north pole of the magnet is called the positive (+), and the south pole, the negative (−). A magnet thus poised constitutes a *magnetic needle.* If we hold a magnet near a magnetic needle, we shall find that the south pole of one attracts the north pole, and repels the south pole of the other.* This proves the law—"*Like poles repel, and unlike poles attract.*"

FIG. 189.

FIG. 190.

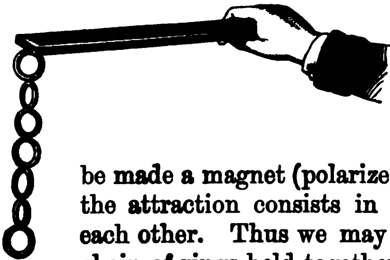


2. Induction is the power a magnet possesses to develop magnetism in iron. If a piece of soft iron be brought near a magnet, it

* **Experiments.** 1. Rub the point of a sewing-needle across the north pole of a magnet. Bring the point near the south pole of the magnetic needle. The needle will be repelled, showing that the point of the sewing-needle has become a south pole. 2. Suspend a key from the north pole of a magnet. Bring the south pole of an equal magnet close to the upper end of the key. The key will instantly fall. 3. Suspend a long iron-wire from the north pole of a magnet. Bring the north pole of the second magnet near the lower end of the wire. The wire is repelled, because its lower extremity possesses north polarity. 4. Immerse the unlike poles of two magnets in iron-filings. Bring the two poles near each other. The filings will move toward one another. But if the poles of the magnets are like, the filings will fall off the magnets. 5. To ascertain whether a metallic substance contains iron: Bring the substance near one of the extremities of a magnetic needle. If the position of the

immediately assumes the magnetic state, but loses it on being removed. In steel the change is permanent. The end of the bar next to the south pole of the magnet becomes the north pole of the new magnet, and *vice versa.* When opposite states are thus developed in the opposite ends of a body, it is said to be ***polarized.*** Whenever an object is attracted by a magnet, it is supposed first to

FIG. 191.



be made a magnet (polarized) by induction, and then the attraction consists in that of unlike poles for each other. Thus we may suspend from a magnet a chain of rings held together by magnetic attraction.* Each link is a magnet with its north and south poles. Each particle of the tuft of filings in Fig. 188 is a distinct magnet. By inducing magnetism, a magnet does not lose force. It rather gains by the reflex influence of the new magnet. An armature acts in this manner to strengthen a magnet. If we break a magnet, the smallest fragment will have a north and a south pole. This is explained by supposing that every molecule contains two kinds of electric force which neutralize each other. When magnetized they are separated, but do not leave the molecule which is thus polarized, the halves assuming opposite magnetic states, as shown in Fig. 192. The light half of each little circle represents the positive, and the dark the negative side. All the molecules exert their negative force in one direction, and their positive in the other. The forces thus neutralize each other at the centre, but manifest themselves at the ends of the magnet.

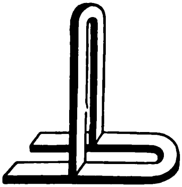
FIG. 192.

needle be affected, then the substance almost certainly contains iron. A piece of copper will not affect the magnetic needle.

* Repeat this experiment with keys, or nails of different sizes, or bits of wire of varying length.

3. How to make a Magnet.—Place the inducing magnet, as shown in Fig. 193, on the unmagnetized one (which any blacksmith can make from a bar of steel), and draw it from one end to the other several times, always carrying it back through the air to the starting-point.*

Fig. 193.



4. The Compass is a magnetic needle used by mariners, surveyors, etc. It is delicately poised over a card on which the "points of the compass" are marked. At most places the

Fig. 194.

needle does not point directly N. and S. The *"line of no variation"* in the United States passes near Wilmington,

* A needle may be magnetized by laying it across the poles of a horse-shoe magnet. After remaining a time the end in contact with the north pole of the magnet will become a south pole and the other a north pole. If it be suspended from the middle by a thread it will point north and south. A knife-blade may be magnetized by rubbing it several times, in the same direction, across one of the poles of the magnet.

N. C., Charlottesville, Va., and Pittsburg, Pa. East of this, the variation (*declination*) is toward the west, and west it is toward the east.*

5. Polarity of the Needle.—WHY THE NEEDLE POINTS NORTH AND SOUTH.—The earth is a great magnet. This gives direction to the needle. Variations which are constantly taking place in the terrestrial magnetism produce corresponding changes in the needle. Suppose a magnet NS passing through the centre of a small globe. The needle *sn* will hang parallel to it (Fig. 195), its north pole being attracted by the south pole of the magnet, and *vice versa*. If the globe be revolved (Fig. 196), the north pole of the needle will turn—*dip*, as it is termed—downward. If the globe be revolved in the other direction, the south pole of the needle will dip in the same manner.†

FIG. 195.

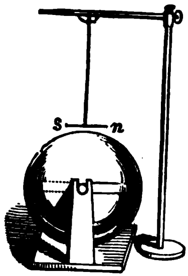


FIG. 196.

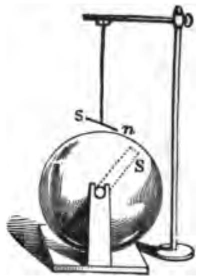
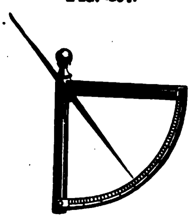


FIG. 197.



A DIPPING-NEEDLE is poised as shown in Fig. 197. At the magnetic equator it hangs horizontally, but declines when carried north, until, at a point called

* The declination and dip have daily and yearly variations, as well as those which require centuries to complete. The needle is, however, "true to the pole," although it shifts thus every hour in the day. It does so only in obedience to the laws which control its action.

† Similar phenomena are noticed in the compass. At the magnetic equator it is horizontal, but *dips* whenever taken north or south. An unmagnetized needle, if poised, in our latitude, on being magnetized, settles down, as if the north end were the heavier. This is remedied by making the north end of the needle lighter, and also by suspending a little weight upon the south end. The reverse is true in the southern hemisphere.

the North magnetic pole, near Hudson's Bay, it becomes vertical.*

6. Magnetism of the Earth.—All iron bars standing vertically (in this latitude not far from the line of the dip) possess slight magnetic properties. Iron fences, lightning-rods, iron standards of chairs and desks, pokers, tongs, crow-bars, etc., on being tested by the magnetic needle, will be found to possess north polarity in the end next the ground, and south polarity in the other.

2. FRICTIONAL ELECTRICITY.

This is electricity developed by friction. Ex.: One's hair often crackles under a gutta-percha comb. A cat's back, when rubbed in a dark room, emits sparks.†

1. The Electroscope is an instrument for detecting the presence of electricity. Bend a glass tube, and suspend from it by silk threads a couple of elder-pith balls, as shown in Fig. 199; or put an egg in a wine-glass, and balance on the egg a dry lath. Two strips of gold-leaf,

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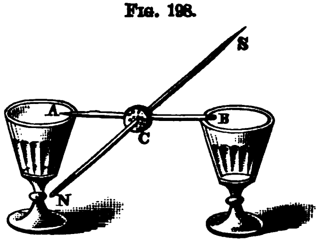
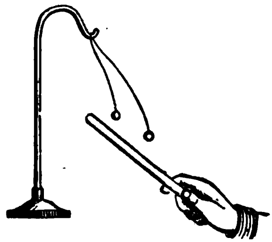
FIG. 198.



* The dipping needle may easily be illustrated. Thrust a knitting-needle NS, through a cork, C, and at right angles insert a fine sewing-needle, AB, to serve as an axis. Place the instrument upon the edges of glasses, as shown in the figure. Push the knitting-needle one way or the other until it will remain horizontal. Now magnetize the knitting-needle, NS, in the manner already described (p. 214). Again place the needle upon the glasses, giving it a north-and-south direction. The north pole of the knitting-needle will dip toward the north.

† In cold, frosty weather, a person, by shuffling about in his stocking-feet upon the carpet, can develop so much electricity in his body that he can ignite a jet of gas by simply applying his finger to it.—Blasts in mines intended to be fired by electricity have thus been prematurely discharged by the workmen touching the wires. To prevent this disastrous effect, at the Sutro Tunnel, Nevada City, the workmen who are handling exploders wet their boots, stand on an iron plate to conduct off the electricity of the body, and wear rubber gloves.

Fig. 199.



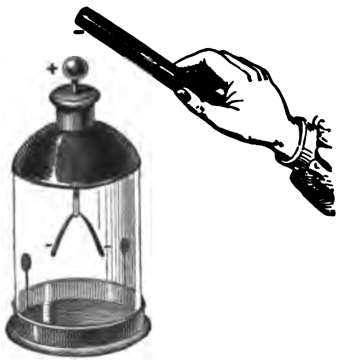
hung in a glass jar (Fig. 200), form a test so sensitive, that a slight flap of a silk handkerchief against the cover will cause the leaves to diverge.

2. Two Kinds of Electricity.—If a warm, dry glass tube (a lamp-chimney will answer) be rubbed with a silk handkerchief, a crackling sound will be heard. If the tube be held near the face, we shall experience a sensation like that of a cobweb. The tube will attract bits of paper, straw, feathers, etc.* Present it to

* The following simple experiments are in tructive: 1. A rubber comb passed a few times through the hair will furnish enough electricity to turn the lath entirely around, and empty egg shells, paper hoops, etc., will follow the comb over the table in the liveliest way. 2. Take a thin sheet of gutta-percha, about a foot square; lay it upon the table, and rub it briskly a few times with an old fur cuff; the gutta-percha will become powerfully electrified. 3. Lift the gutta-percha by one corner, and some force will be required to separate it from the table. 4. Hold the electrified gutta-percha in the left hand; bring the fingers of the right near the paper; it will be attracted to the hand, and sparks will pass to the fingers with a snapping sound. 5. Hold some feathers, suspended by a silk thread, near the excited gutta-percha and the feathers will be attracted. 6. Hold the excited paper, or the excited sheet of gutta-percha, over the head of a person with dry hair; the hair will be attracted by the gutta-percha, and each particular hair will stand on end. 7. Hold the excited gutta-percha near the wall; the gutta-percha will fly to it, and remain some minutes without falling. 8. Place a sheet of gutta-percha on a tea-tray; rub the gutta-percha briskly with a fur cuff: place the tea-tray with the excited sheet of gutta-percha on a dry tumbler; lift off the gutta-percha from the tea-tray: bring the knuckle of your hand near the tray, and you will receive a spark. Replace the gutta-percha on the tray and apply your knuckle, and you will receive another spark. This may be repeated a dozen times. 9. Take a sheet of foolscap paper and a board about the same size. Heat both till they are thoroughly dry. While hot, lay the paper on the board and rub the former briskly with a piece of rubber. The paper and board will cling together. Tear the paper loose and try experiments 4, 5, 6 and 7. Return the paper and rub as before. Cut the paper so as to form a tassel. Then lift, and the strips of the tassel will repel one another. 10. Take a piece of common brown paper, about the size of an octavo book, hold it before the fire till quite dry and hot, then draw it briskly under the arm several times, so as to rub it on both sides at once by the coat. The paper will be found so powerfully electrical, that if placed against a wainscoted or papered wall of a room, it will remain there for some minutes without falling. 11. While the paper still clings to the wall hold against it a light, fleecy feather and it will be attracted to the paper, in the same way the paper is to the wall. 12. If the paper be warmed, drawn under the arm as before, and then hung up by a thread attached to one corner, it will sustain several feathers on each side; should these fall off from different sides at the same time, they will cling together very

the pith-balls in the electroscope. They will be attracted for an instant, and will then fly from the tube and from each other, apparently in disgust. Electrify a stick of sealing-wax and present it to the balls. They will act in the same manner. If we touch one ball with the excited glass, and the other with the excited wax, they will not, as before, fly from each other, but will rush together. Present the glass to a ball; it will fly off when electrified. Present the glass again, and it will be repelled. Substitute the wax, and it will be attracted. Offer now the glass, and it will eagerly bound toward what it just before spurned.

FIG. 200.



strongly; and if after a minute they are all shaken off, they will fly to one another in a singular manner. 13. Warm and excite the paper as before, and then lay on it a ball of elder-pith, about the size of a pea; the ball will immediately run across the paper, and if a needle be pointed toward it, it will again run to another part, and so on for a considerable time. 14. Support a pane of glass, well dried and warmed, upon two books, one at each end, and place some bran underneath; then rub the upper side of the glass with a silk handkerchief, or a piece of flannel, and the bran will dance up and down like the images in Fig 207. 15. Place a common tea-tray on a dry, clean tumbler. Then take a sheet of foolscap writing-paper (as in No. 9) and dry it carefully until all its hygrometric moisture is expelled. Holding one end of the sheet on a table with the finger and thumb, rub the paper with a large piece of india-rubber a dozen times vigorously from left to right, beginning at the top. Now take up the sheet by two of the corners and bring it over the tray, and it will fall like a stone. This, as well as the apparatus in No. 8, forms a simple *Electrophorus*, fit to perform many experiments ordinarily performed with that instrument. If the tip of a finger be held close to the bottom of the tray, a sensible shock will be felt. Next lay a needle on the tray with its point projecting outward, remove the paper, and, in the dark, a star sign of the negative electricity will be seen; return the paper, and the positive brush will appear. Lay a dry, hot board, as in No. 9, on top of four tumblers. If a boy stand on the board he will be insulated, and on his holding the tray vertically, the paper will not fall. Sparks may then be drawn from his body, and his hair will be electrified as described on p. 230. 16. Warm a lamp-chimney, rub it with a hot flannel, and then bring a downy feather near it. On the first moment of contact, the feather will adhere to the glass, but soon after will fly rapidly away, and you may drive it about the room by holding the glass between it and the surrounding objects; should it, however, come in contact with anything not under the influence of electricity, it will instantly fly back to the glass.

If the glass be held on one side of a ball and the wax on the other, it will fly between the two, carrying the electricity back and forth. From this we conclude that (1), there are two kinds of frictional as of magnetic electricity; and (2), *like electricities repel each other, and unlike attract.* The electricity from the glass is termed vitreous or positive [+], and that from the wax, resinous or negative [—].*

3. Theory of Electricity.—Of the nature of electricity we know little. The positive and negative forces, or fluids, as they are often styled, exist in every body in a state of equilibrium. When this is disturbed by friction, chemical action, etc., both are set free. We cannot develop one without the other. The opposite kinds manifest themselves at opposite parts of the surface, as in a magnet; it is therefore a *polar force.* The slightest cause disturbs the electric equilibrium. "In cutting a slice of meat, there may pass between the steel knife and the silver fork enough electricity to move the needle of a telegraph." Yet the delicate balance of the opposing forces is so soon readjusted that we are unconscious of the change.

4. Conductors and Insulators.—A body which allows the electric force to pass through it freely is termed a *conductor;* one which does not, is called a *non-conductor,* or *insulator.* Copper is one of the best conductors, and hence it is used in all electrical experiments. Glass is one of the best insulators. A body is said to be insulated when it is supported by some non-conducting substance, usually glass. Electricity can be collected only by insulation. In damp air electricity is quickly dissipated. This, according to the recent experiments of Wm. Thomson, is due to the deposit, on the glass insulators, of a thin film of moisture, which

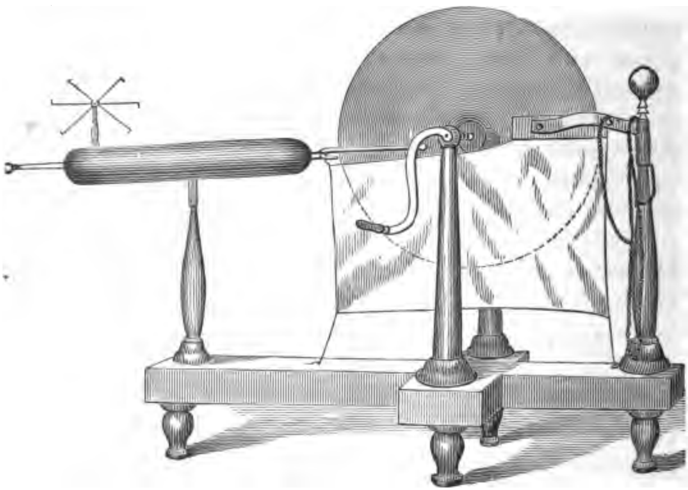
* In the following list, each substance becomes positively electrified when rubbed with the body following it; but negatively, with the one preceding it. (*Ganot.*)

1. Cat's fur.	5. Cotton.	9. Shellac.	13. Caoutchouc.
2. Flannel.	6. Silk.	10. Resin.	14. Gutta-percha.
3. Ivory.	7. The hand.	11. The metals.	15. Gun-cotton.
4. Glass.	8. Wood.	12. Sulphur.	

conducts away the electricity. Contrary to the common statement, there *is no difference between dry and damp air as an insulator.**

5. The Electrical Machine consists (1) of a glass *wheel* turned by a crank; (2) of a pair of *rubbers* covered with leather and spread with an amalgam (a mixture of tin, zinc, and mercury) which hastens the development of electricity; (3) of a *comb* or fork with fine points, since pointed

FIG. 201.



bodies always favor the reception or dispersion of electricity; (4) of a *prime conductor*—a brass cylinder insulated by a glass standard so that the electricity cannot pass to the

* The following list contains the most common conductors and insulators:

Best Conductors.		*Best Insulators.*	
Metals.	Vegetables.	Shellac.	Air (dry or damp).
Charcoal.	Animals.	Amber.	Dry Paper.
Flame.	Linen.	Sulphur.	Caoutchouc.
Minerals.	Cotton.	Wax.	Ice.
Water.	Dry Wood.	Glass.	Dry Wood.
Iron.	Ice.	Silk.	Cotton.

ground, and rounded at the ends so that it may not escape too rapidly into the atmosphere.

At the commencement, the whole apparatus is in a state of equilibrium. By friction, positive electricity is developed on the glass, and negative on the rubber. The negative escapes along the chain to the ground—the common reservoir. The positive, kept on the glass by the silk flaps, is carried around to the points. Here it polarizes the prime conductor, *i. e.*, repels its positive electricity to the far end and attracts its negative electricity to the points; the two forces, clashing together, form tiny sparks and are neutralized.* The positive electricity naturally present in the prime conductor is thus left insulated, and the prime conductor is said to be *charged* with positive electricity. If the negative conductor be insulated, the rubber will soon become charged with negative electricity, and the action of the machine will nearly cease.

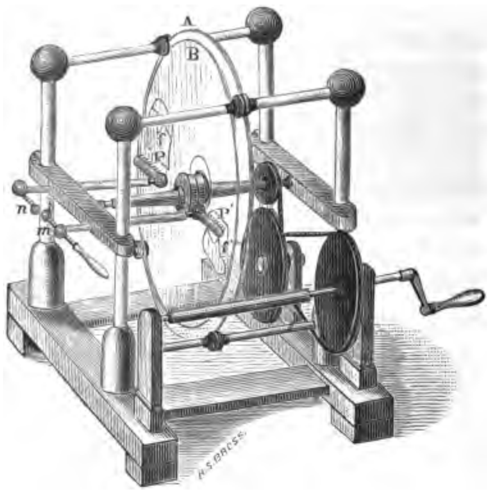
HOLTZ'S ELECTRICAL MACHINE is shown in Fig. 202. AB are two plate-glass wheels, the former fixed and the latter made to revolve by turning the handle. In A are two openings or *windows*. Near these are glued two pieces of varnished paper or *armatures*, *f f'*, each of which has a point projecting through the window. Opposite the armatures, and on the other side of the revolving wheel, are two rows of brass points, P P'. Connected with these are insulated conductors terminating in the movable knobs *mn*, the *poles* of the machine.

In starting, the poles are placed in contact, and one of the armatures is electrified by holding against it a piece of excited rubber or attaching it by a wire to the conductor of an ordinary electrical machine. On then separating the poles, a brilliant discharge of electricity occurs. The usual

* If the rubber be freshly spread with amalgam, and the glass well rubbed with warm flannel, a sharp crackling noise will be heard, flashes will follow the wheel, while sparks can be obtained from the prime conductor at a distance of several inches. The pith-ball electroscope, when charged and repelled by the prime conductor, will be quickly attracted by the rubber, thus indicating their opposite electricities.

explanation is as follows: "The two armatures are electrified, one positively and the other negatively. The positive armature (say f') is opposite to that conductor which gives off positive electricity from its knob *m*, and the positive which escapes from the knob is replaced by positive which is drawn off by the points from the face of the revolving plate, an action which is favored by the inductive

FIG. 202.



influence of the positively-charged armature, whether we regard it as repelling positive from the plate to the brass points, or as attracting negative from the conductor through the brass points. The plate, having thus given off positive or received negative electricity, is carried round through half a revolution, and gives off negative to the other conductor through its brass points, aided by the influence of the negatively-charged armature at the back."

6. Induction.*—The influence of an electrified body

* The experiments in Fig. 203 can be nicely performed by means of an egg placed flatwise on the top of a dry wine-glass and the glass tube used on p. 217. Several eggs and glasses will show the principle of Fig. 204. See Tyndall's Lessons on Electricity, p. 39.

over other bodies near it is termed *electrical induction.* Thus, let an insulated conductor be placed near the end of the prime conductor of an electrical machine. On charging the prime conductor the motion of the pith-balls shows that the small conductor has also become charged, the end next the positive prime conductor being negative, and the other end positive. As opposite electricities are thus developed at the opposite extremities of the conductor, it is *polarized.* Place several conductors, as shown in Fig. 204, connecting the copper

FIG. 203.

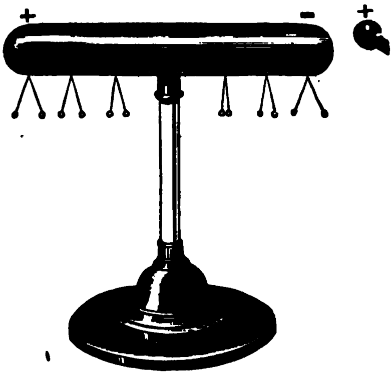
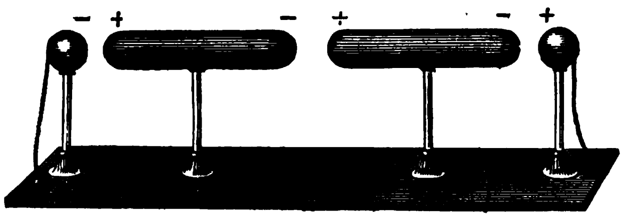


FIG. 204.



ball at the right with the positive pole, and the one at the left with the negative pole of the electrical machine. The conductors will be charged and polarized by induction.

FARADAY'S THEORY OF INDUCTION assumes (1) that the electricity acts between the different molecules of a body, as between the different conductors in the last experiment—that each molecule becomes polarized, and in turn polarizes its neighbors, and that thus at last every molecule has opposite electricities on its opposite sides; (2) that the

molecules of non-conductors become polarized and ***retain*** their electricities, while the molecules of conductors become polarized and *discharge* their electricities into the adjacent molecules. The positive force thus accumulates at one end, and the negative at the other. Let P (Fig. 205) represent the end of the positive conductor and N that of the small conductor in Fig. 203; and let the small circles represent molecules of air lying between the two—the lighter half indicating the positive and the darker half the negative side. The molecules of air being non-conducting, on being polarized from the influence of P, the prime conductor, retain their electricities, but polarize one another in succession until N is reached. This being a conducting body, its molecules impart their electricity from one to the other, until the negative electricity collects at one end and the positive at the other.

FIG. 205.

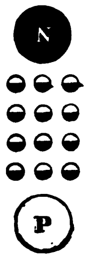
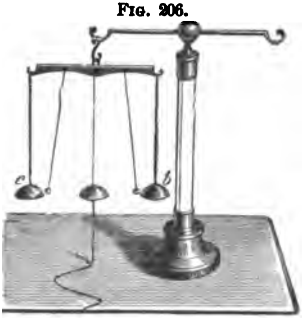


FIG. 206.



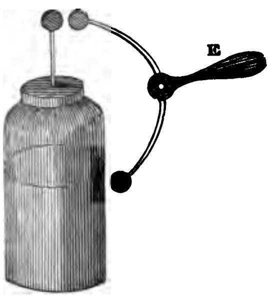
7. Attraction and Repulsion.—Every case of attraction or repulsion is preceded by induction. Ex.: "The *electric chime*" consists of three bells, two of which, *c* and *b*, are hung by brass chains, while the middle one is insulated above by a silk cord, and connected below with the earth by a chain. The balls between them are also insulated. The outer bells becoming charged with positive electricity from the prime conductor, polarize the balls by induction through the intervening air. The balls being then attracted to the bells, are charged and immediately repelled. Swinging away, they strike against the middle bell, discharging their electricity, and are forthwith attracted again. Flying to and fro, they ring out a merry, electrical song.

The *dancing image* consists of a pith-ball figure placed between two metallic plates, the upper one hanging from the prime conductor, and the lower one connected with the earth. The dance is conducted by alternate attraction and repulsion.*

FIG. 207.

8. The Leyden Jar† consists of a glass jar coated inside and outside, nearly to the top, with tinfoil. It is fitted with a cover of baked wood, through which passes a wire with a knob at the top, and below, a chain extending to the inner coating. The jar is *charged* by bringing the knob near the prime conductor of the electrical machine, while the outer coating communicates with the earth. Bright sparks will leap to the inner coating, while similar ones will pass off from the outer coating. The jar is *discharged* by holding one knob of the "discharger" E, upon the outer coating, and the other upon the knob of the jar. The equilibrium will be restored with a sharp snap and a brilliant flash. Minute

FIG. 208



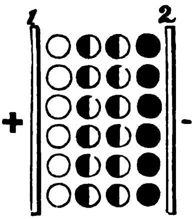
* A slow motion should be given to the electrical wheel, and a pin thrust into the heel of the image will add much to the stamp of the tiny feet.

† It is said that Cuneus, a pupil at Leyden, discovered the principle of the Leyden jar in the following curious way: While experimenting, he held a bottle of water to the prime conductor of his electrical-machine. Noticing nothing peculiar, he attempted to investigate its condition. Holding the bottle with one hand, he happened to touch the water with the other, when he received a shock so unexpected, and so unlike anything he had ever felt before, that he was filled with astonishment. It was two days before he recovered from his fright. A few days afterward, in a letter to a friend, the physicist innocently remarked, that he would not take another shock for the whole kingdom of France.

particles detached from the solid conductors burn, giving color and brilliancy to the spark.*

Explanation.—The essentials of the jar are ***two conducting surfaces separated by a non-conducting body.*** The tin-foil acts only as a conductor to convey the electricity.† The jar is charged on the same principle as the prime conductor of the electrical machine. The positive prime conductor draws out the negative electricity of the inner coating, leaving it charged with positive. The molecules of glass are polarized (Fig. 209). A like quantity of positive electricity then escapes from the outer coating. If the jar be insulated so that this is unable to leave, the passage of the sparks will cease. If a finger be held near the outer coating, a spark will leap to it every time one enters the jar. The jar, therefore, when charged, contains no more electricity than in its natural state. It is only differently distributed.

Fig. 209.



9. Electricity is on the Surface.—Each molecule within the surface of a solid, insulated conductor gives up its electricity with equal freedom in every direction; therefore it cannot become charged. Each molecule on the surface, however, receiving electricity from the particles behind it, and having non-conducting particles of air before it, must become charged. A bomb-shell can therefore hold as much electricity as a cannon-ball.

10. Effect of Points.—A pointed wire held near the prime conductor will quietly draw off all its electricity,

* The incredibly small quantity of the metal volatized in this way is a striking proof of the divisibility of matter. During some experiments at the Philadelphia mint a gold pole lost in weight by a strong spark one millionth of a grain; and $\frac{1}{3500000}$ of a grain of nickel *signed its name* in the spectroscope brilliantly. See *Popular Science Monthly*, May, 1877.

† This is illustrated by the "Leyden jar with movable coatings," which may be charged and then taken apart. Very little electricity can be obtained from the glass, the tin coatings, or any two of the parts combined. When put together again, the jar can be discharged in the usual manner.

which will be seen apparently clinging to the point like a glowing star. If we fasten a pointed wire to the prime conductor, it will silently discharge the electricity in a "brush" of flame. If we hold one cheek near the point, we shall feel a current of air setting away from it. This is strong enough to deflect the flame of a candle. The particles of air near the point becoming polarized, are attracted, give up their negative electricity, and, being charged with positive electricity, are repelled; new ones take their place, and thus a current is established.*

11. Lightning is only the discharge of a Leyden jar on the grand scale upon which Nature performs her operations. Two clouds charged with opposite electricities, and separated by the non-conducting air, approach each other.† When the tension becomes sufficient to overcome the resistance, the two forces rush together with a blinding flash and terrific peal. The lightning moves along the line of the least resistance, and so describes a zigzag course. If we can trace the entire length, we call it *chain-lightning;* if we see only the flash through intervening clouds, it is *sheet-lightning;* and if the reflection of distant discharges, we term it *heat-lightning.* The report is caused by the clashing of displaced air. The rolling of the thunder is produced by the reflection of the sound from distant clouds. Sometimes the clouds and the earth become charged with opposite electricities, separated by the non-conducting air. The spark from the discharge of this huge Leyden jar is a bolt that often causes fearful destruction.

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* The *electric whirl*, mounted on the prime conductor (Fig. 201), illustrates this action. As each molecule of air is repelled from a point, it reacts with equal force against the point. This is sufficient to set the light wire-wheel in rapid rotation.

† The air is almost constantly electrified by the friction of moving clouds, winds, etc., by heat and chemical changes—all of which disturb the equilibrium. In clear weather it is in a positive state, but in foul weather it changes rapidly from positive to negative, and *vice versa*. Dr. Livingstone tells us that in South Africa the hot wind which blows over the desert is so highly electrified, that a bunch of ostrich feathers held for a few seconds against it becomes as strongly charged as if attached to an electrical-machine, and will clasp the hand with a sharp crackling sound.

The AURORA BOREALIS * ("Northern Lights") is probably caused by the passage of electricity through the rarefied atmosphere of the upper regions. The intimate relation between the aurora and magnetism is shown from the fact

FIG. 210.

that the magnetic needle is disturbed when the aurora is visible, and seems to tremble as the streamers dart to and fro. The telegraph is frequently worked by the current of electricity which passes along the wire on these occasions.

LIGHTNING-RODS were invented by Franklin.† They are based on the principle that electricity always seeks the best

* It may be beautifully imitated, on a small scale, by passing a succession of sparks from the prime conductor through the rarefied air contained in a long glass tube, shown in Fig. 29.

† Franklin's plan was opposed by many philosophers of the day, who declared it was as impious to ward off Heaven's lightning, "as for a child to ward off the chastening rod of its father." There was much discussion as to whether the conductors should be pointed or not. Wilson persuaded George III. that the points were a republican device to injure His Majesty, as they would certainly "invite" the lightning, and so the points on the lightning-rods upon Buckingham Palace were changed for balls.

conductor. The rod should be pointed at the top with some metal which will not easily corrode. If constructed in separate parts, they should be securely jointed. The lower end should extend into water, or else deep into the damp ground, beyond a possibility of any drought rendering the earth about it a non-conductor, and be packed about with ashes or charcoal. If the rod is of iron, it needs to be much larger than one of copper, which is a better conductor. Every elevated portion of the building should be protected by a separate rod. Chimneys need especial care, because of the ascending column of vapor and smoke. Water conductors, tin roofs, etc., should be connected with the damp ground or the lightning-rod, that they may aid in conveying off the electricity.*

12. Velocity of Electricity.—The duration of the flash has been estimated at one-millionth of a second. Some idea of its instantaneousness can be formed from the fact that the spokes of a wheel, revolved so rapidly as to become invisible by daylight, can be distinctly seen by the spark from a Leyden jar. The trees swept by the tempest, or a train of cars in rapid motion, when seen by a flash of lightning, seem motionless; while a cannon-ball, in swift flight, appears poised in mid-air.†

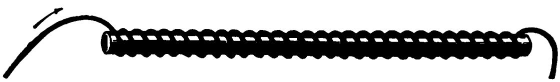
13. Effects of Frictional Electricity.—(1.) PHYS-

* The value of a lightning-rod consists, most of all, in its power of quietly restoring the equilibrium between the earth and the clouds. By erecting lightning-rods, we thus lessen the liabilities of a sudden discharge. Providence has guarded largely against this catastrophe. "God has made a harmless conductor in every leaf, spire of grass, and twig. A common blade of grass, pointed by Nature's exquisite workmanship, is three times more effectual than the finest cambric needle, and a single pointed twig than the metallic point of the best-constructed rod." Every drop of rain, and every snowflake, falls charged with the electric force, and thus quietly disarms the clouds of their terror. The balls of electric light, called by sailors "*St. Elmo's fire*," which sometimes cling to the masts and shrouds of vessels, and the flames seen to play about the points of bayonets, indicate the quiet escape of the electric force from the earth toward the clouds.

† Recent investigations indicate that electricity has no fixed velocity, but that its rate depends on its intensity and the medium through which it passes. Prof. Rood, of Columbia College, has produced sparks whose duration was forty-one billionths of a second.

ICAL.—Discharges from a large battery of Leyden jars will melt metal rods, perforate glass, split wood, magnetize steel bars, etc.—Let a person stand upon an insulated stool and become charged from the prime conductor. His hair, through repulsion, will stand erect in a ludicrous manner. On presenting his hand to a little ether contained in a warm spoon, a spark leaping from his extended finger will ignite it. If he hold in his hand an icicle, the spark will readily dart from it to the liquid.*—A card held between the knob of a Leyden jar and that of the discharger, will be punctured by the spark.—A piece of steel may be magnetized by the discharge from a Leyden jar. Wind a covered copper

FIG. 211.



wire around a steel bar, as in Fig. 211, or enclose a needle in a small glass tube, around which the wire may be wound.

FIG. 212.

On passing the spark through the wire, the needle will attract iron-filings.—When strips of tinfoil are pasted on glass, and figures of various curious patterns cut from them, the electric spark leaping from one to the other presents a beautiful appearance.—If a battery be discharged through a wire too small to conduct the spark, the electricity will be changed to heat, and if sufficiently small, the wire will be fused into globules or dissipated in smoke.†

(2.) CHEMICAL EFFECTS.—The "electric gun" is filled with a mixture of oxygen and hydrogen gases. A spark

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* This experiment can be more surely performed by using di-sulphide of carbon. The insulating stool may be merely a board laid on four dry flint-glass bottles or goblets, and the electricity be developed by rubbing a glass tube, as on p. 217.

† The fact that the electric force is thus converted into vibrations of heat and light, would seem to indicate that, like them, it is only a mode of motion.

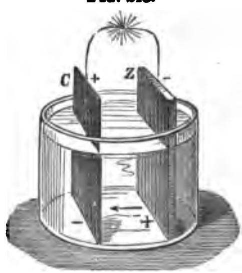
causes them to combine with a loud explosion and form water.—The sulphurous smell which accompanies the working of an electrical machine, and is noticed in places struck by lightning, is owing to the production of ozone, a peculiar form of the oxygen of the air. (See *Chemistry*, p. 38.)

(3.) Physiological Effects.—A slight charge from a Leyden jar produces a contraction of the muscles and a spasmodic sensation in the wrist. A stronger one becomes painful and even dangerous.

3. GALVANIC OR VOLTAIC ELECTRICITY.*

1. Simple Galvanic Circuit.†—If we place a strip of zinc in water acidulated with sulphuric acid (oil of vitriol), a chemical action will at once commence. Bubbles of hydrogen gas gather on the metal, while the zinc rapidly dissolves.‡ Now put a strip of copper in the liquid. While the two metals remain separate no change takes place, but as soon as they touch, or are connected by wires, as in the figure, chemical action begins, and the bubbles of hydrogen gather upon the copper instead of, as before, upon the zinc. The copper is unchanged, but the zinc wastes away. As soon as the wires are separated the action ceases, and when they are rubbed together in the dark, a minute spark is seen.

Fig. 218.



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* These names are given in honor of the two Italian philosophers who made the first discoveries in this branch of electricity. (See p. 251.)

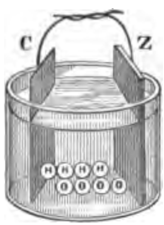
† We can easily form a simple galvanic circuit by placing a silver coin between our teeth and upper lip, and a piece of zinc under our tongue. On pressing the edges of the two metals together, a peculiar taste will be perceived, while a flash of light will pass before the closed eyes.

‡ If we immerse the zinc in mercury, the surface will become as bright as a mirror. Replace the strip in the cup, and the acid will have no effect upon it as long as the current does not pass. The reason of this action is not well understood. Zinc used in galvanic batteries is thus amalgamated.

Two metal plates combined in this manner form a *galvanic pair.* The ends of the wires are termed *poles* or *electrodes.* The copper pole is positive and the zinc negative.* Joining the wires is termed *closing the circuit,* and separating them, *breaking the circuit.*

2. Why the Hydrogen comes from the Copper.—For simplicity of illustration, we suppose a row of water molecules † extending from the zinc to the copper plate. The negative oxygen of the molecule of water nearest the positive zinc is attracted to that plate, while the positive hydrogen is repelled. The atom thus driven off seeks refuge with the oxygen of the next molecule, and dispossesses its hydrogen. This atom in turn robs the third molecule of its oxygen, and so on until the last molecule is reached, when the atom of hydrogen, attracted by the negative copper, gives up to it its positive electricity, and then flies off into the air. Each atom of escaping hydrogen imparting its electrical force, adds to the current of electricity.

FIG. 214.



3. Galvanic Current.—The word "current" should not be understood to indicate the passage of a fluid, like the flow of water in a stream, but a mere transmission of the electrical force. Thus, if a long pipe were perfectly filled with water, a drop added at one end would thrust out a corresponding one at the other, which would not, however,

* These names may easily be remembered if we associate the p's with copper and positive, and the n's with zinc and negative. It should be noticed that the terms are reversed when applied to the plates and the poles The zinc pole is negative, but the zinc plate is positive; the copper pole is positive, but the copper plate is negative. We thus see that the plates when placed in the liquid become polarized, as is represented in Fig. 213.

† In Fig. 214 a molecule of water is represented, for convenience, as consisting of only one atom of hydrogen and one of oxygen, instead of two of hydrogen and one of oxygen.—Late investigators hold that the hydrated sulphuric acid (H_2SO_4), rather than the water alone, is decomposed, the hydrogen going to the copper and the sulphuric acid combining with the zinc. (See replacement theory, *Chemistry*, p. 51.)

be the identical one dropped in, since the force alone would traverse the length of the pipe. In the galvanic pair the current of positive electricity sets out from the positive zinc through the liquid to the negative copper, thence through the wire around again to the zinc. If the circuit be broken, the current will manifest itself at the copper pole.* When the current passes through a conducting substance, as a wire, rod, etc., the force is transmitted, not on the surface, but through the *entire thickness of the body.* Each molecule, becoming polarized and charged, discharges its force into the next molecule, and so on. The current thus moves by a rapid succession of polarizations and discharges of the molecules of the conductor.†

4. **Electrical Potential** is a property of a body by which electricity tends to go from it to another, and is measured by the resistance met in the passage. This term is to electricity what temperature is to heat. When plates of zinc and copper are brought in direct contact, or are connected by means of the liquid, they assume different *electrical potentials* as already seen (Fig. 213). On joining the wires, the electricity passes from the body at the higher potential to the one at the lower. This constitutes the current, which is made a steady flow by the constant chemical decomposition taking place. The greater the difference between the chemical action upon the two metals the stronger the current. The metal most corroded is termed the positive or generating plate, and the one least corroded the negative or collecting plate.

5. **A battery** consists of several galvanic pairs, combined so as to increase the strength and steadiness of the electric current.

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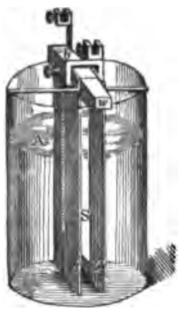
* There is also a negative current passing in the opposite direction; but, to avoid confusion, whenever the term current is used, the positive is intended.

† With what inconceivable rapidity must these successive changes take place in an iron wire to transmit the electric force, as in recent experiments, from Valentia, Ireland, across the bed of the Atlantic and the continent to San Francisco and return, a distance of 14,000 miles, in two minutes! In fact, it distanced the sun, and leaving Valentia at 7:21 A.M., Feb. 1, it reached San Francisco at 11:20 P.M., Jan. 31.

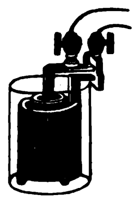
SMEE'S BATTERY.—Each cell consists of two plates of zinc and one of silver suspended between them. They are clamped together with screws and hung in a glass jar filled with dilute sulphuric acid. Since bubbles of hydrogen gas tend to collect on the smooth surface of the silver and interrupt the action, it is roughened with finely-divided platinum.

FIG. 215.



GROVE'S BATTERY is a "two-fluid battery." The outer or glass jar contains dilute sulphuric acid, in which is placed a hollow zinc cylinder with a slit at the side to allow a free circulation of the liquid. The inner cup is of porous earthenware, and filled with strong nitric acid (aqua fortis), in which is suspended a thin strip of platinum.*

FIG. 216.



BUNSEN'S BATTERY differs from Grove's in substituting a carbon rod for the platinum strip in the inner cup. This, being an excellent conductor, answers the same purpose and is cheaper.

DANIELL'S CONSTANT BATTERY has an outer copper cup

* The chemical change is as follows: The water in the outer cup is decomposed, the oxygen uniting with the zinc and the sulphuric acid with both, to make sulphate of zinc. The hydrogen, however, does not escape, as in Smee's battery, but passes into the inner cup and tears apart the nitric acid, forming water and nitric oxide. (See *Chemistry*, p. 46.) The latter is at first absorbed by the liquid, but soon begins to escape in corrosive, blood-red fumes. According to the new nomenclature in Chemistry, the sulphuric acid, H_2SO_4, is decomposed, the hydrogen passing into the inner cup and the anhydrous acid combining with the zinc. If the zinc is properly amalgamated, no action takes place while the poles are separated, and the battery remains quiescent, like a sleeping giant, but the instant the wires are connected the liquid will begin to boil with the evolution of the gas, while the electric force will leap to the poles. The advantages of this battery are: (1.) The hydrogen does not collect on the negative (platinum) plate, since it is absorbed by the nitric acid. (2.) The liquid formed in the inner cup is an excellent conductor of electricity. (3.) Platinum is a more perfect negative metal than copper, since it is not acted upon by the acid, and thus does not tend to start a counter-current; therefore platinum and zinc make a better voltaic pair than copper and zinc. (4.) The additional decomposition of the nitric acid sets free a great quantity of electricity.

holding a solution of blue vitriol, and an inner porous cup containing a zinc rod and dilute sulphuric acid. *The sulphate of copper battery* consists of a large zinc cylinder suspended in a copper jar containing a solution of copper sulphate (blue vitriol).

6. Quantity and Intensity.—A battery may develop a great quantity of electricity having a low degree of intensity, or a small quantity having a high intensity. Thus a cup of boiling water is intensely hot, while a hogshead of lukewarm water contains a great quantity of heat. The intensity of the electric force depends on the *number* of cells; the quantity, on their *size*. An intensity battery is formed by joining the zinc plate of one cell to the copper of the next; a quantity battery, by joining the zinc and the copper plates together.

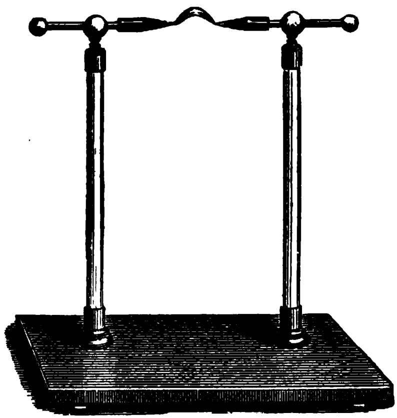
7. Comparison of Frictional with Galvanic Electricity.—Frictional electricity is noisy, sudden, and convulsive; galvanic is silent, constant, and powerful.* The one is a quick, violent blow; the other a steady, uniform pressure. Intensity is the characteristic of the former, quantity of the latter. The lightning will leap through miles of intervening atmosphere, while the galvanic current will follow a conductor around the globe, rather than jump across the gulf of a half-inch of air. The most powerful frictional machine would be insufficient for telegraphing; while despatches have been sent across the ocean with a tiny battery composed of "a gun-cap and a strip of zinc, excited by a drop of water the bulk of a tear."

* To decompose a grain of water would require over 6,000,000 discharges from a Leyden jar—enough electricity to charge a thunder-cloud 35 acres in area; yet a few galvanic cups would tear apart that amount of water in perfect ease and silence. "Faraday immersed a voltaic pair, composed of a wire of platinum and one of zinc, in a solution of 4 ozs. of water and one drop of oil of vitriol. In three seconds this produced as great a deviation of the galvanometer needle (Fig. 220) as was obtained by 30 turns of the powerful plate-glass machine. If this had been concentrated in one millionth of a second, the duration of an electric spark, it would have been sufficient to kill a cat; yet it would require 800,000 such discharges to decompose a grain of water."

8. Effects of Galvanic Electricity.—(1.) PHYSICAL. If a current of electricity is passed through a wire too small to conduct it readily, it is converted into heat. The poorer the conducting power of the wire, and hence the greater the resistance, the more marked the effect. With 10 or 12 Grove's cups several inches of fine steel wire may be fused; and with a powerful battery, several yards of platinum wire made glowing hot.*

In closing or breaking the circuit we produce a spark, the size of which depends on the intensity of the current. With several cells, beautifully variegated sparks are obtained by fastening one pole to a file and rubbing the other upon it. When charcoal or gas-carbon electrodes are used with a powerful battery, on slightly separating the points, the intervening space is spanned by an arch of the most dazzling light (Fig. 217). The flame, reaching out from the positive pole like a tongue, vibrates around the negative pole, licking now on this side and now on that. The heat is intense. Platinum melts in it like wax in the flame of a candle,† the metals burn with their characteristic colors; and lime, quartz, etc., are fused.

FIG. 217.



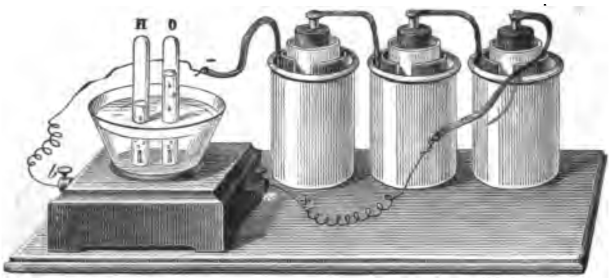
* Torpedoes and blasts are fired on this principle. Two copper wires leading from the battery to the spot are separated in the powder by a short piece of small steel-wire. When the circuit is completed, the fine wire becomes red-hot and explodes the charge.

† To show the varying conducting power of the different metals, fasten together alternate lengths of silver and platinum wire and pass the current through them. The latter will glow while the former conveying the electricity more perfectly will scarcely manifest its presence.

The effect is not produced by burning the charcoal points, since in a vacuum or even under water it is equally brilliant.

(2.) CHEMICAL EFFECTS.—*Electrolysis* (to loosen by electricity) is the process of the decomposition of compound bodies by the voltaic current. If platinum electrodes be held a little distance apart in a cup of water, tiny bubbles

FIG. 218.



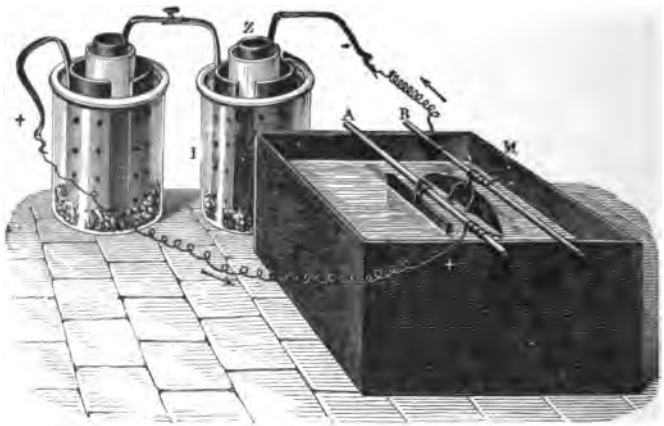
will immediately begin to rise to the surface. When the gases are collected, they are found to be oxygen and hydrogen, in the proportion of two parts of the latter to one of the former.* In the electrolysis of compounds, their elements are found to be in different electrical conditions. Hydrogen and most of the metals go to the negative pole, and (since unlike electricities attract) are *electro-positive.* Oxygen, chlorine, sulphur, etc., go to the positive pole, and are therefore *electro-negative.*

Electrotyping is the process of depositing metals from their solution by electricity. It is used in copying medals, woodcuts, types, etc. An impression of the object is taken

* If the copper poles be inserted, bubbles will pass off from the negative, but none from the positive pole, since the oxygen combines with the copper wire. That gas has no effect on platinum. The burning of an atom of zinc in the battery develops enough electricity to set free an atom of oxygen at the positive pole. This indicates a very intimate relation between chemical affinity and electricity—perhaps even their identity. It is interesting to notice that in the battery there is zinc burning, *i. e.*, combining with oxygen, but without light or heat; in the electric light the real force of the combustion is revealed. We may thus transfer the light and heat to a great distance from the fire.

with gutta-percha or wax. The surface to be copied is brushed with black-lead to render it a conductor. The mould is then suspended in a solution of copper sulphate, from the negative pole of the battery, and a plate of copper is hung opposite on the positive pole. The electric current

FIG. 219.



decomposes the copper sulphate; the metal goes to the negative pole and is deposited upon the mould, while the acid, passing to the positive pole, dissolves the copper, and preserves the strength of the solution.*

Electro-plating is the process of coating with silver or gold by electricity. The metal is readily deposited on German silver, brass, copper, or nickel silver (a mixture of copper, zinc, and nickel). The objects to be plated are thoroughly cleansed, and then hung from the negative pole in a solution

* While the plate is hanging in the solution there is no noise heard or bubbling seen. The most delicate sense fails to detect any movement. Yet the mysterious electric force is continually drawing particles of *ruddy*, *solid* copper out of the *blue liquid*, and, noiselessly as the fall of snowflakes, dropping them on the mould; producing a metal purer than any chemist can manufacture, spreading it with a uniformity no artist can attain, and copying every line with a fidelity that knows no mistake.

of silver, while a plate of silver is suspended on the positive pole. In five minutes a "blush" of the metal will be deposited, which conceals the baser metal and is susceptible of polish.*

(3.) PHYSIOLOGICAL EFFECTS.—With a single cell no effect is experienced when the two poles are held in the hands. With a large battery a sudden twinge is felt, and the shock becomes painful and even dangerous, especially if the palms are moistened with water to increase the conduction. Rabbits which had been suffocated for half an hour, have been restored to life by an application of the galvanic current.

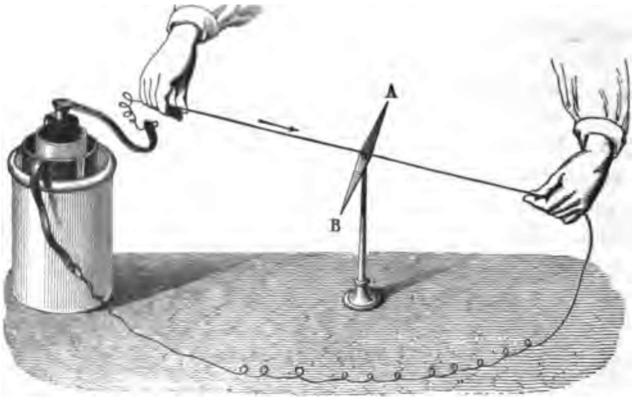
4. ELECTRO-MAGNETISM.

1. Effect of a Galvanic Current on a Magnetic Needle.—If a current of electricity be passed over a magnetic needle, the needle will tend to place itself at right angles to the wire. If the wire is brought over and beneath the needle, it doubles the effect, and the play of the needle

* Place in a large test-tube a silver coin with a little aqua-fortis. If the fumes of the decomposed acid do not soon rise, warm the liquid. When the silver is dissolved fill the tube nearly full of soft water. Next drop muriatic acid into the liquid until the white precipitate (silver chloride) ceases to fall. When the chloride has settled, pour off the colored water which floats on top. Fill the tube again with soft water; shake it thoroughly; let it settle, and then pour off as before. Continue this process until the liquid loses all color. Finally, fill with water and heat moderately, adding potassium cyanide (the pupil will remember that this substance is exceedingly poisonous) in small bits as it dissolves, until the chloride is nearly taken up. The liquid is then ready for electro-plating. Thoroughly cleanse a brass key, hang it from the negative pole of a small battery and suspend a silver coin from the positive pole. Place these in the silver solution, very near and facing each other. When well whitened by the deposit of silver remove the key and polish it with chalk. In the arts the polishing is performed by rubbing with "burnishers." These are made of polished steel, and fit the surfaces of the various articles upon which they are to be used. It is said that an ounce of silver can be spread over two acres of surface. A well-plated spoon receives about as much silver as there is in a ten-cent piece. The only method of deciding accurately the amount deposited is by weighing the article before and after it is plated.—A vessel may be "gold-lined" by filling it with a solution of gold, suspending in it a slip of gold from the positive pole of the battery, and then attaching the negative pole to the vessel. The current passing through the liquid causes it to bubble like soda-water, and in a few moments deposits a thin film of gold over the entire surface.

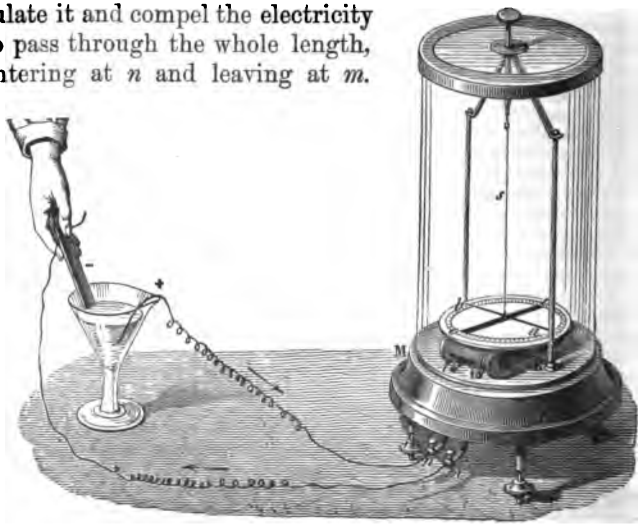
becomes a delicate test of the presence and direction of the electric force.

FIG. 220.



2. The Galvanometer is an instrument for measuring the force and direction of an electric current. B is a coil of wire, wound with thread to insulate it and compel the electricity to pass through the whole length, entering at *n* and leaving at *m*.

FIG. 221.

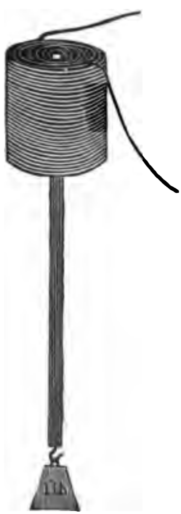


The silk cord, *s*, supports an *astatic needle.* This consists of two magnetic needles, one over the graduated circle and the other within the coil, with the north pole of the one opposite the south pole of the other, so as to neutralize the attraction of the earth, and permit the combined needle to obey the will of the current alone.

FIG. 222.

3. Electro-magnets.—The galvanic current produces magnetism. If a current be passed through the wire shown in Fig. 211, the steel bar will be rendered magnetic. This shows the identity of the electricity from the galvanic battery with that from the Leyden jar. If the wire be wound around a bar of soft iron, as in Fig. 222, the iron will instantly become a magnet which will grasp the armature with great force, but will as quickly lose its properties when the current is broken. If the current be passed through a coil of insulated wire (*helix*) (Fig. 223), a rod of iron held below it will be drawn up forcibly, as if pulled by a powerful spring.* Here we see that not only does the soft iron within become magnetic, but also the coil itself.

FIG. 223.



4. Motion Produced by Electricity.—If we reverse the direction of the current, we change the poles of the magnet. Advantage is taken of this to produce continuous motion. Fig. 224 represents *Page's Rotating Machine.* It consists of

* Thus is realized in science the fabulous story of Mahomet's coffin, which is said to have been suspended in mid-air.

an upright horse-shoe magnet, between the poles of which is a small electro-magnet. Above this are two springs,

Fig. 234.

which are so placed that, as the central rod revolves with the electro-magnet, the current passes through these springs, alternately, to the wire coiled about the iron of the electro-magnet. The poles of the electro-magnet are thus changed twice with each revolution. The poles of the upright magnet attract the opposite poles of the electro-magnet, but as soon as they face each other the current is reversed, and they at once repel each other; the other poles are then attracted, but as they come together are repelled as before. A rapid motion is thus secured. The revolutions may rise as high as 2,500, making 5,000 reversals of the current in a minute.

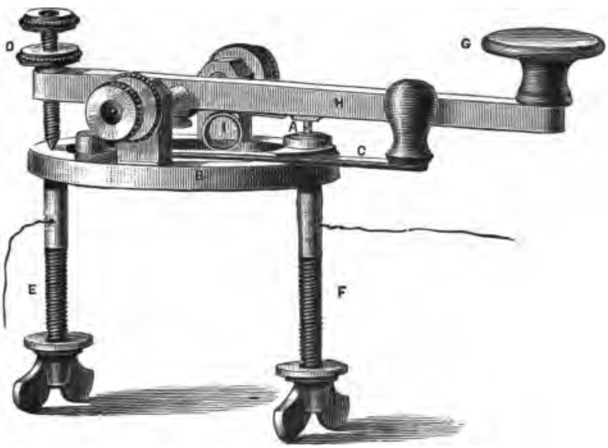
Electro-magnetic Engines are constructed either on the principle that the magnet retains its power only while the current is passing, or that the poles are changed by reversing the current. They have been made of 8 or 10 horse-power, but have never become of great practical value, because of the expense of the battery required to produce the electricity. The zinc which burns in the cell of the electric-engine is far more expensive than the coal which burns in the furnace of the steam-engine.

The Electro-magnetic Telegraph depends on the principle of closing and breaking the circuit at one station, and thereby making and unmaking an electro-magnet at the station to which the despatch is to be sent. A single wire is used to connect the two stations. The extremities of the wire extend into the ground, and the earth completes the circuit. Each station has a key and a register (or sounder);

the former is used for sending messages, and the latter for receiving them.

The key is shown in Fig. 225. E and F are screws which fasten the instrument to the table, and also hold the two ends of the wire. F is insulated by a rubber ring where it passes through the table B. H is a lever with a finger-button G, a spring I, to keep it lifted, and a screw D, to regulate the distance it can move. At A is a break between two platinum points, which form the real ends of the wire.

FIG. 225.

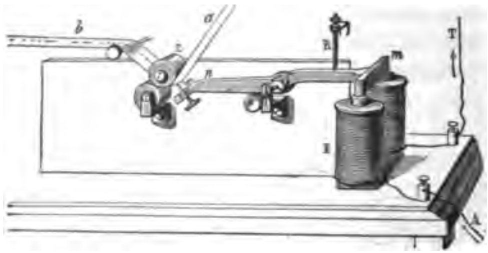


When G is depressed, the circuit is complete, and when lifted, it is broken. C is a *circuit-closer* that is used when the key is not in operation; the arm being pushed under A touches the platinum wire and so completes the circuit. The operator, by moving G, can "close" or "open" the circuit at pleasure. He thus sends a message.

The *register* contains an electro-magnet, E (Fig. 226). When the circuit is complete, the current, flashing through the coils of wire at E, attracts the armature *m*. This elevates *n*, the other end of tne lever *mn*, and forces the sharp point *x* firmly against the soft paper *a*. As soon as the

circuit is broken, E ceases to be a magnet, and the spring R lifts the armature, drawing the point from the paper. Clock-work attached to the rollers at z moves the paper along uniformly beneath the point x. When the circuit is

FIG. 226.



completed and broken again instantly, there is a sharp dot made on the paper. This is called *e*; two dots, *i*; three dots, *s*; four dots, *h*. If the current is closed for a longer time, the mark becomes a dash, *t*; two dashes, *m*; a dot and a dash, *a*.

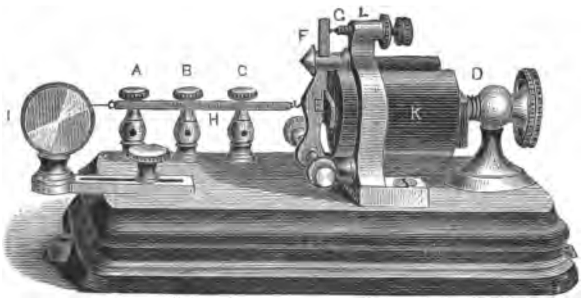
TABLE OF MORSE'S SIGNS.

a · —	j — · — ·	s · · ·
b — · · ·	k — · —	t —
c · · ·	l ——	u · · —
d — · ·	m — —	v · · · —
e ·	n — ·	w · — —
f · — ·	o · ·	x · — · ·
g — — ·	p · · · · ·	y · · · ·
h · · · ·	q · · — ·	z · · · ·
i · ·	r · · ·	& · · · ·

A skilful operator becomes so used to the sound that the clicking of the armature is perfectly intelligible. He uses, therefore, simply a "*sounder*," *i. e.*, a register without the paper and clock-work attachment.

RELAY.—When the stations are more than fifty miles apart, the current becomes too weak to work the register. The *relay* uses the force of a local battery for this purpose.

FIG. 227.



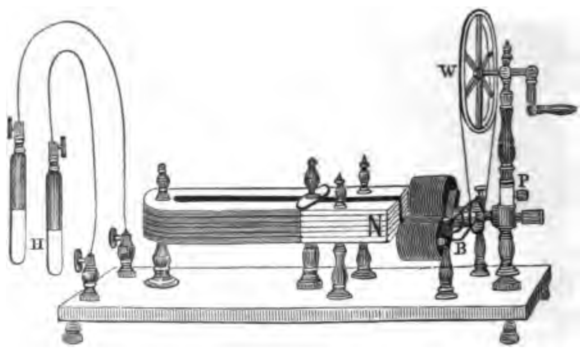
D is the line-wire; C the ground-wire; A is connected with the positive pole; and B with the register or sounder and thence with the negative pole of the battery. The current passes in at D, traverses the fine wire of the electro-magnet, K, and thence passes out at C to the ground. The armature E, playing to and fro as the current from the distant station darts through or is cut off, moves the lever F. This works on an axis at the lower end and is drawn back by the spring H, which is regulated by the thumb-screw I. As E is attracted the circuit at G is closed; the current from A leaps through a wire underneath, up F, and down L and back through another wire underneath to B, and thence to the electro-magnet of the register, and attracts its armature.

The operator who sends the message simply completes and breaks the circuit with the *key;* the *armature* of the *relay,* at the station where the message is received, vibrates in unison with these movements; the *register* or *sounder* repeats them with greater force; and the second operator interprets their meaning.

5. Magneto-electricity is developed by means of magnetism. A machine for this purpose is shown in Fig.

228. Coils of wire are insulated and wound around a small bar of soft iron, B, bent at right angles. This acts as the armature of a powerful horse-shoe magnet, before the poles of which it revolves. The soft iron becomes magnetic, and then induces electric currents in the coils. The poles are

FIG. 228.



changed twice, and thus two opposite currents are induced in each revolution. By means of a break-piece the circuit is rapidly broken and closed. Severe shocks are thus produced, when the poles are grasped by the hands.*

6. Induced Currents.—Let two coils of wire be made to fit into each other, and carefully separated by insulators. If a current of electricity be passed through the inner coil, it will induce a powerful secondary current, flowing in the

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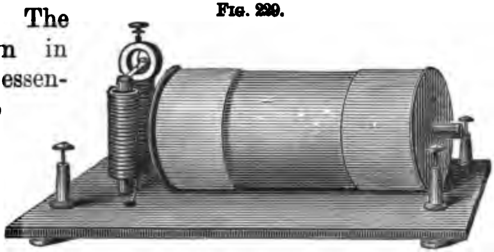
* In Wild's machine, the induced current from the coils acts upon a large electro-magnet, which is thereby excited to a high degree. A machine driven by a steam-engine of 15-horse power produces an electric light dazzling as the noonday sun, throwing the flame of the street-lamps into shade at a quarter-mile distance. Its heat is sufficient to fuse a ¼-inch bar of iron fifteen inches long or 7 feet of No. 6 iron wire.—" A Yankee once threw the industrial world of Europe into a wonderful excitement by announcing a new theory of perpetual motion based on the magneto-electric machine. He proposed to decompose water by the current of electricity; then burn the hydrogen and oxygen thus obtained. In this way he would drive a small steam-engine, which, in turn, would keep the magneto-electric machine in motion. This would certainly be a splendid discovery. It would be a steam-engine which would prepare its own fuel, and, in addition, dispense light and heat to all around." (Helmholtz.)

opposite direction, in the outer coil. This soon ceases; on breaking the circuit, however, it will start again, but in the same direction as the primary current. The apparatus shown in Fig. 229 consists essentially of the two coils just described. The primary current from a single cell is rapidly interrupted by means of a small electro-magnet. When this is magnetized, it attracts the armature, and thus the circuit is broken; the armature immediately springs back, and again completes the circuit. A bunch of iron wires may be inserted as a core in the inner coil. When the current passes, these become magnetized, and by induction strengthen the secondary current. *Ruhmkorff's coil* is constructed on the same principle. The largest coils often contain thirty to fifty miles of covered wire. They will throw a quick succession of sparks, 20 to 40 inches long, so as to charge and discharge a Leyden jar, with a crack like that of a pistol, as rapidly as one can count.*

FIG. 229.



7. **The Telephone**† (sound afar), in the Bell instrument, consists of a magnet N, S, at one end of which is a coil of wire C, a thin iron plate B, and a mouth-piece A.

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* They are also used to illustrate the effects of the passage of electricity through the various gases and rarefied vapors. These are placed in sealed glass tubes, known as Geissler's tubes, and when the current passes they exhibit the richest tints and bands of color.

† A telephone in parts, ready to be put together by the experimenter, is sold by the apparatus dealers. A simple but effective instrument can be made, at a slight expense, by a pupil with ordinary mechanical ability. One process, with illustrative drawings, is given in the Popular Science Monthly, March, 1878, and another in the Scientific American, Vol. 39, No. 5. In Vol. 39, No. 16, is also described a method of constructing a microphone; and in the Scientific American Supplement, No. 138, is an account of a home-made phonograph. These numbers can be procured by any newsdealer. In using the telephone, two instruments exactly alike are employed. One is held to the mouth of the speaker, and the other to the ear of the listener

The ends of the coil are connected, the one with a line wire and the other with the earth or a return wire. At the second station is a similar instrument. The vibrations of the voice at A throw the plate into vibration. As B approaches N the magnet is strengthened and a current of electricity induced in the coil C and thence transmitted to the line wire. When B recedes from N the current is stopped. Thus the waves of air are translated into corresponding waves of electricity.* At the other station the reverse process occurs. The pulses of electricity are there converted into waves of air which, falling upon the ear at A, produce the phenomena of sound.

Fig. 230.

Fig. 231.

8. The Microphone † consists of a small battery for generating a weak current of electricity, a telephone for the

* It should be noticed that in the apparatus described in the note on p. 127, the sound is conveyed by mechanical vibrations merely, while in the true telephone they are transmitted by electrical pulsations.

† The microphone is to the telephone what the microscope is to the telescope. The microphone enables us to hear minute sounds, and the telephone conveys sounds to a great distance; just as the microscope permits us to see minute objects, and the telescope distant ones.

receiving instrument, and a transmitting or speaking instrument. The last may be a small rod of gas carbon* (Fig. 231), with the ends set loosely in blocks of the same material; the latter are attached to an upright support glued into a wooden baseboard. This instrument is connected with the battery and the telephone. A sound made near the rod can be heard at the distant telephone, with wonderful distinctness. The patter of a fly's foot in walking across the baseboard, or the brush of a camel's-hair pencil, is audible many miles away.

5. THERMAL ELECTRICITY.

As electricity can be changed into heat, heat can in turn be converted into electricity.

A Thermo-electric Pile consists of alternate bars of antimony and bismuth soldered together, as shown in Fig. 233. When mounted for use, the couples are insulated from each other and enclosed in a copper frame P. If both faces of the pile are equally heated, there is no current. The least variation of temperature, however, between the two is indicated by the flow of electricity. Wires from *a*, the positive pole, and *b*, the negative, connect the pile with the galvanometer (Fig. 221). This constitutes a delicate test of the presence of heat. A fly walking over the face of the pile by its warmth will move the needle.†

FIG. 232.

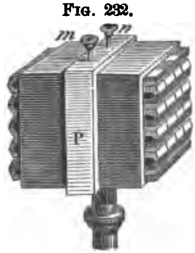
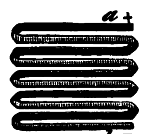


FIG. 233.



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* Instead of the carbon rod, Edison, the famous electrician, has used three nails, the battery of wires being wound around two while the third was laid loosely upon the ends of the others so as to complete the circuit.

† Strange, that minute quantities of heat become sensible only when they are converted into electricity, then into magnetism, and lastly into motion.

6. ANIMAL ELECTRICITY.

Electric Fish have the property of giving, when touched, a shock like that from a Leyden jar. The torpedo and the electrical eel are most noted. The former is a native of the Mediterranean, and its shock was anciently prized as a cure for various diseases. The latter is abundant in certain South American waters. A specimen of this fish, forty inches in length, was estimated by Faraday to emit a spark equal to the discharge of a battery of fifteen Leyden jars. The Indians are said to drive herds of wild horses into the streams frequented by the fish. The horses are soon overpowered by the terrible shocks they receive, and so fall an easy prey to their pursuers.

SUMMARY.

Electricity is a form of energy which is excited by means of magnetism, friction, chemical action, heat, and also by induction or the presence of other electrified bodies. It possesses a peculiar duality or doubleness of property, as seen in the alternate attraction and repulsion of magnetic poles. These two forms of the same force are called positive and negative. Magnetism is manifested only at the ends of a body, while electricity may reside equally over its entire surface. Magnetism is, however, identical with electricity, and they have a reciprocal relation. Magnets of soft iron may be made of any strength by means of the electrical currents. The earth itself is doubtless a great magnet, made so by electrical currents which circulate about it, being generated perhaps largely by the heat of the sun. This accounts for the polarity of the needle which is so useful in navigation. Electricity may be developed in any quantity by means of friction, combined, as in Holtz's machine, with induction. It may be hoarded for use by the Leyden jar, the construction of which curiously illustrates the phenomena of lightning.

Galvanic electricity is born of metallic difference and chemical action. The essentials of an ordinary battery for its development are two substances, one of which is more strongly acted on by a chemical agent, while the other gathers the electricity set free. It differs from frictional electricity in being characterized by quantity rather than intensity; in flowing in a continuous current rather than a sudden discharge; in traveling along a wire to any desired distance; in being

perfectly manageable, and in manifesting its properties at any point where the current is interrupted. It has a powerful chemical or inter-atomic action, breaking up the molecules of compound bodies as seen in the decomposition of water and the various processes of electrotyping, plating, etc. The electric telegraph, the telephone, the microphone and the use of the electric light for illumination, are the latest applications of the electric force to the purposes of practical life.

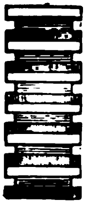
HISTORICAL SKETCH.

Thales (6th cent. B. C.), one of the seven wise men, knew that when amber is rubbed with silk it will attract light bodies, as straw, leaves, etc. This property was considered so marvellous that amber was supposed to possess a soul. From the Greek name of the substance (elektron) our word electricity is derived. This simple phenomenon constituted all that was known until the 16th century, when Gilbert, physician to Queen Elizabeth, made some valuable experiments. The next century Guericke discovered induction. Then Newton turned his powerful mind upon the subject and is thought by some to have invented a glass-globe electrical machine. In the 18th century, Du Fay accounted for electrical phenomena by the theory of two fluids—the vitreous and the resinous. This view is yet held by many and its nomenclature has permeated the whole subject of electricity so that we still speak of a "current," a "flow of electricity," etc.

About 1752, Franklin proved the identity of lightning and frictional electricity by means of a kite made of a silk handkerchief and with a pointed wire at the top. He elevated this during a thunderstorm, tying at the end of the hemp string a key, and then insulating the whole by fastening it to a post with a long piece of silk lace. On presenting his knuckles to the key, he obtained a spark. So great was his joy, that he is said to have burst into tears. He afterwards charged a Leyden jar, and performed other electrical experiments in this way. These attempts were attended with very great danger. Prof. Richman, of St. Petersburg, drew in this manner from the clouds a ball of blue fire as large as a man's fist which struck him lifeless.

In the year 1790 Galvani was engaged in some experiments on animal electricity. For this purpose he used frogs' legs as electroscopes. He had hung several of these upon *copper* hooks from the *iron* railing of the balcony, in order to see what effect the atmospheric electricity might have upon them. He noticed, to his surprise, that when the wind blew them against the iron supports, the legs were convulsed as if in pain. After repeated experiments,

Fig. 233.



Galvani concluded that this effect was produced by what he termed animal electricity, that this electricity is different from that caused by friction, and that he had discovered the agent by which the will controls the muscles. Volta rejected the idea of animal electricity, and held that the contact of dissimilar metals was the source of the electricity, while the frog was "only a moist conductor, and for that purpose was not as good as a wet rag." He applied this view to the construction of "Volta's pile," which is composed of plates of zinc and copper, between which are laid pieces of flannel moistened with an acid or a saline solution (Fig. 233). This theory is substantially the one held at the present time, though we now know that there must be chemical action to continue the supply.

Electricity and magnetism were studied as distinct branches until 1820, when Oersted of Copenhagen discovered the phenomenon shown in Fig. 220. This was published everywhere, and excited the deepest interest of scientific men. In the fruitful mind of Ampère the experiment bore abundant fruit. He discovered that two parallel wires conveying electricity in the same direction attract each other, and when in opposite directions, repel each other. From this he generalized the entire subject. Prof. Henry next exhibited the wonderful power of the electro-magnet, and invented the electro-magnetic engine. Scientific men in all parts of the world were now gathering the material necessary for the invention of the electric telegraph. It fell to Samuel F. B. Morse to make this knowledge practical, and in 1837 he exhibited in New York a working instrument. An experimental line between Washington and Baltimore was completed in 1844, and, on May 27th of that year, was sent the first message ever forwarded by a recording telegraph.

Consult Maxwell's "Electricity and Magnetism"; Tyndall's "Lessons in Electricity"; Faraday's "Lectures on the Physical Forces" and "Researches in Electricity"; Noad's "Manual of Electricity"; Art. on the Microphone, in Scribner's Monthly, Vol. XVI, p. 600; Prescott's "The Speaking Telephone, Talking Phonograph," etc.; Foster's "Electrical Measurements," in Science Lectures at South Kensington, Vol. I, p. 264; Thomson's "Papers on Electrostatics and Magnetism"; Guillemin's "The Forces of Nature" and "The Applications of Physical Forces"; "American Cyclopædia," Articles on Electricity, Magnetism, Electro-magnetism, etc.; Smith's "Manual of Telegraphy"; Jones's "Historical Sketch of Electric Telegraph"; Watts's "Electro-metallurgy"; "Barnes's Hundred Years of American Independence," Sec. on Morse, p. 442; "Fourteen Weeks in Zoology," Sec. on Torpedo, p. 186.

CONCLUSION.

"Science is a psalm and a prayer."—PARKER.

NOWHERE in nature do we find chance. Every event is governed by fixed laws. If we would accomplish any result or perform any experiment, we must come into exact harmony with the universal system. If we deviate from the line of law by a hair's breadth, we fail. These laws have been in operation since the creation, and all the discoveries of science prove them to extend to the most distant star in space. A child of to-day amuses itself with casting a stone into the brook and watching the widening curves; little antediluvian children may have done the same. A law of nature has no force of itself; it is but *the manner in which force acts.*

We cannot create force. We can only take it as a gift from God. We find it everywhere in Nature; so that matter is not dumb, but full of inherent energy. A tiny drop of dew sparkling on a spire of grass is instinct with power: Gravity draws it to the earth; Chemical Affinity binds together the atoms of hydrogen and oxygen; Cohesion holds the molecules of water, and gathers the drop into a globe; Heat keeps it in the liquid form; Adhesion causes it to cling to the leaf. If the water be decomposed, Electricity will be set free; and from this, Heat, Light, Magnetism, and Motion can be produced. Thus the commonest object becomes full of fascination to the scientific mind, since in it reside the mysterious forces of Nature.

These various forces can be classified either as attractive or repellent. Under their influence the atoms or molecules resemble little magnets with positive and negative poles. They therefore approach or recede from one another, and so tend to arrange themselves according to some definite

plan. "The atoms march in time, moving to the music of law." A crystal is but a specimen of "molecular architecture" built up by the forces with which matter is endowed. Forces continually ebb and flow, but the sum of energy through the universe remains the same. In time all the possible changes may be rung, and the various forms of energy subside into one uniformly-diffused heat-quiver, but in that will exist the representation of all the forces which now animate creation, and, as we believe, matter and force will perish only together.

The forces of Nature are strangely linked with our lives. Everywhere a Divine Hand is developing ideas tenderly and wondrously related to human needs. To the thoughtful mind all phenomena have a hidden meaning.

> "To matter or to force
> The all is not confined;
> Beside the law of things
> Is set the law of mind;
> One speaks in rock and star,
> And one within the brain,
> In unison at times,
> And then apart again.
> And both in one have brought us hither,
> That we may know our whence and whither.
>
> "The sequences of law
> We learn through mind alone;
> We see but outward forms,
> The soul the one thing known;
> If she speak truth at all,
> The voices must be true
> That give these visible things,
> These laws, their honor due,
> But tell of One who brought us hither,
> And holds the keys of whence and whither.
>
> "He in His science plans
> What no known laws foretell;
> The wandering fires and fixed
> Alike are miracle:
> The common death of all,
> The life renewed above,
> Are both within the scheme
> Of that all-circling love.
> The seeming chance that cast us hither
> Accomplishes His whence and whither."

X.

APPENDIX.

QUESTIONS.

The following questions are those which the author has used in his classes, both as a daily review and for examination. A standing question, which has followed every other question, has been: "*Can you illustrate this?*" Without, therefore, a particular request, the pupil has been accustomed to give as many practical examples as he could, whenever he has made any statement or given any definition. The figures refer to the pages of the book.

I. **Introduction.**—Define matter. A body. A substance. Name and define the two kinds of properties which belong to each substance. State the suppositions of the Atomic Theory. What is a molecule? An atom?

14. Describe the two kinds of change to which matter may be subjected. What is the principal distinction between Philosophy (Physics) and Chemistry? Mention some phenomena which belong to each. Why are these branches intimately related?

15. Name the general properties of matter. Define magnitude. Size. Distinguish between size and mass.* (See notes, pp. 21, 53.) Why are feathers light and lead heavy? Why is it necessary to have a standard of measure? What are the French and English standards?

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* "In a rude age, before the invention of means for overcoming friction, the weight of bodies formed the chief obstacle to setting them in motion. It was only after some progress had been made in the art of throwing missiles, and in the use of wheel-carriages and floating vessels, that men's minds became practically impressed with the idea of mass as distinguished from weight. Accordingly, while almost all the metaphysicians who discussed the qualities of matter, assigned a prominent place to weight among the primary qualities, few or none of them perceived that the sole unalterable property of matter is its *mass*. At the revival of science this property was expressed by the phrase 'The inertia of matter;' but while the men of science understood by this term the tendency of the body to persevere in its state of motion (or rest), and considered it a measurable quantity, those philosophers who were unacquainted with science understood inertia in its literal sense as a quality—mere want of activity or laziness. I therefore recommend to the student that he should impress his mind with the idea of mass by a few experiments, such as setting in motion a grindstone or a well-balanced wheel, and then endeavoring to stop it, twirling a long pole, etc., till he comes to associate a set of acts and sensations with the scientific doctrines of dynamics, and he will never afterward be in any danger of loose ideas on these subjects."—*Maxwell's Theory of Heat*, p. 85.

Give the history of the English standard. (See pp. 23, 24.) Is the American yard an exact copy of the English? Give an account of the French system. By what name is this system commonly known? Is either of these systems founded on a natural standard? Why is it desirable to have such a standard?

16–17. Define Impenetrability. Give some apparent exceptions, and explain them. Define Divisibility. Is there any limit to the divisibility of matter? Define Porosity. Is the word *porous* used here in its common acceptation? Compare the size of an atom or a molecule with that of a pore. What practical use is made in the arts of the property of porosity? Describe the experiment of the Florence academicians.

18. Define Inertia. Does a ball, when thrown, stop itself? Why is it difficult to start a heavy wagon? Why is it dangerous to jump from the cars when in motion? (Compare First Law of Motion, p. 28.) Define Indestructibility. Did the earth, at its creation, contain the same quantity of matter that it does now?

19. Name the specific properties of matter. Define Ductility. How is iron wire made? Platinum wire? Gilt wire? Define Malleability.

20. Describe the manufacture of gold-leaf. Is copper malleable? Define Tenacity. Name and define the three kinds of Elasticity. Illustrate the elasticity of compression as seen in solids. In liquids. In gases. What is said about the relative compressibility of liquids and gases?

21. Illustrate the elasticity of expansion as seen in solids, liquids, and gases. Define Elasticity of Torsion. What is a Torsion balance? Define Hardness. Does this property depend on density? Define Density. Define Brittleness. Is a hard body necessarily brittle? Name a brittle and a hard body.

II. **Motion and Force.**—Define motion, absolute and relative. Rest. Velocity. Force. What are the resistances to motion? Tell what you can about friction. Why does oil diminish friction? (See p. 39.) What uses has friction? What law governs the resistance of air or water? Define Momentum.

28–30. Show that motion is not imparted instantaneously. State the three laws of motion and the proof of each. If a ball be fired into the air when a horizontal wind is blowing, will it rise as high as if the air were still? Describe the experiments with the collision balls. Give practical illustrations of action and reaction. If a bird could live, could it fly in a vacuum? Define compound motion.

31. Define the so-called "parallelogram of forces." The resultant. How can the resultant of two or more forces be found? Name some

practical illustrations of compound motion. What is the "resolution of forces?"

32. Show how one vessel can sail south and another north, driven by the same westerly wind. Explain how a kite is raised. Explain the "split-shot" in croquet.

33. Explain the towing of a canal-boat. Describe how motion in a curve, and circular motion are produced. Explain the centripetal and centrifugal forces.

34. Show when the centrifugal force becomes strong enough to overcome the force of Cohesion. Of Adhesion. Of Gravity. Apply the principle of circular motion to the revolution of the earth about the sun. What effect does the revolution of the earth on its axis have upon all bodies on the surface?

35. What would be the effect if the rotation were to cease? Describe the action of the centrifugal force on a hoop rapidly revolved on its axis. What is the Gyroscope? Define reflected motion.

36. Give its law. What is Energy, in the Physical sense of the word? To what is it proportional? Name and define the two forms of energy. How may one form be changed into the other?

37. What is the law of the Conservation of Energy? What did Faraday say with regard to this law (p. 40)?

III. Attraction. I. MOLECULAR FORCES.—Define a molecular force. What two opposing forces act between the molecules of matter? How is this shown? What is the repellent force? Name the attractive forces. Which of these belong to Physics?

1. COHESION.—Define. What are the three states of matter? Define. How can a body be changed from one state to another?

44. Show that cohesion acts only at insensible distances. Explain the process of welding. Why cannot all metals be welded? Why do drops of dew, etc., take a globular form? Why do not all bodies have this form? Illustrate the tendency of matter to a crystalline structure.

45. Has each substance its own form? Why is not cast-iron crystalline? Why do cannon become brittle after long use?

46. Describe the process of tempering and annealing. Explain the Rupert's Drop. How is glassware annealed?

2. ADHESION.—Define. What is the theory of filtering through charcoal? Of what use is soap in making bubbles? Define Capillary Attraction. Why will water rise in a glass tube, while mercury will be depressed? Is a tube necessary to show capillary attraction? What is the law of the rise in tubes?

48. Give practical illustrations of capillary action. Why will not

old cloth shrink as well as new, when washed? What is the cause of solution? Why is the process hastened by pulverizing?

49. Tell what you can about gases dissolving in water. Why does the gas escape from soda-water as soon as drawn? Why do pressure and cold favor the solution of a gas? Describe the diffusion of liquids. Of gases.

50–1. Describe the osmose of liquids. Of gases. Why do rose-balloons lose their buoyancy? What is the difference between the *osmose* and the *diffusion* of gases?

II. GRAVITATION.—How does Gravitation differ from Cohesion and Adhesion? What is the law of gravitation? Why does a stone fall to the ground? Will a plumb-line near a mountain hang perpendicularly? Why do the bubbles in a cup of tea gather on the side? How is the earth kept in its place? Define Gravitation. Gravity. Weight.

53. State the three laws of weight What is a vertical or plumb-line?

54–5. State the four laws of falling bodies. Describe the "guinea-and-feather experiment." What does it prove? * Give the equations of falling bodies.

56. How can the time of a falling body be used for determining the depth of a well? How does gravity act upon a body thrown upward? What velocity must be given to a ball to elevate it to any point? How high will it rise in a given time? When it falls, with what force will it strike the ground? Define the Centre of Gravity. The line of direction. The three states of equilibrium.

57–8. How may the centre of gravity be found? Give the general principles of the centre of gravity. Describe the leaning tower of Pisa. State some physiological applications of the centre of gravity. Why do fat people always walk so erect?

59–60. Define the Pendulum. Arc. Amplitude. What are isochronous vibrations. State the three laws of the pendulum. Who discovered the first law? (See p. 65.) What is the centre of oscillation? † How is it found? What is the centre of percussion?

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* "It is difficult for many pupils to understand how, under the influence of gravity alone, all bodies fall with equal rapidity. An illustration, which is usually effective, is that of a number of bodies of the same kind, say bricks, which will separately fall in the same space of time. The pupil will admit that, if all of them are connected together, inasmuch as nothing is thereby added to their weight, there is no reason why the mass of bricks should not fall in the time of a single one, notwithstanding it is a larger body."—*Wm. H. Taylor.*

† "Take a flat board of any form and drive a piece of wire through it near its edge, and allow it to hang in a vertical plane, holding the ends of the wire by the finger and thumb. Take a small bullet, fasten it to the end of a thread, and allow the thread to pass over the wire so that the bullet hangs close to the board. Move the

61–2. Describe the pendulum of a clock. How is a clock regulated? Does it gain or lose time in winter? Describe the gridiron pendulum. The mercurial pendulum. Name the various uses of the pendulum. Describe Foucault's experiment.

IV. The Elements of Machines.—Name and define the elements of machinery. Do the "powers," so called, produce energy? What is the law of mechanics? Illustrate the law. What is a lever? Describe the three classes of levers. The law of equilibrium.

71. What is the advantage peculiar to each class? Describe the steelyard as a lever. What effect does it have to reverse the steelyard? Describe the arm as a lever. (See *Physiology*, p. 48.) Would a lever of the first class answer the purpose of the arm? Describe the compound lever.

72–3. The hay scale. The wheel and axle. Its law of equilibrium. Describe a system of wheel-work. At which arm of the lever is the P. applied?

74. Describe the various uses of the inclined plane. Its law of equilibrium. What velocity does a body acquire in rolling down an inclined plane? Give illustrations.

75–6. Describe the screw. Its uses. Its law of equilibrium. How may its power be increased? What limit is there? Describe the wedge. Its uses. Its law of equilibrium. How does it differ from that of the other powers? Describe the pulley. The use of fixed pulleys. Is there any gain of P. in a fixed pulley?

77–8. What is the use of a movable pulley. Describe a movable pulley as a lever. Give the general law of equilibrium in a combination of pulleys. What part of the force is lost by friction? What are cumulative contrivances? Is perpetual motion possible?

V. Pressure of Liquids and Gases. 1. HYDROSTATICS.—Define. What liquid is taken as the type? What is the first law of liquids? Explain. Illustrate the transmission of pressure by water. Show how

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hand by which you hold the wire horizontally in the plane of the board, and observe whether the board moves forward or backward with respect to the bullet. If it moves forward, lengthen the string, if backward, shorten it till the bullet and the board move together. Now mark the point of the board opposite the centre of the bullet, and fasten the string to the wire. You will find that, if you hold the wire by the ends and move it in any manner, however sudden and irregular, in the plane of the board, the bullet will never quit the marked spot on the board. Hence this spot is called the centre of oscillation, because, when the board is oscillating about the wire when fixed, it oscillates as if it consisted of a single particle placed at the spot. It is also called the centre of percussion, because, if the board is at rest and the wire is suddenly moved horizontally, the board will at first begin to rotate about the spot as a centre."—*J. Clerk Maxwell, on Matter and Motion*, p. 104.

water is used as a mechanical power. Describe the hydrostatic press. Give its law of equilibrium.

86–90. What are the uses of this press? What pressure is sustained by the lower part of a vessel of water, when acted on by gravity alone? How does this pressure act? State the four laws which depend on this principle, and illustrate them. What is the weight of a cubic foot of sea water? Fresh water? What is the pressure at two feet? Give illustrations of the pressure at great depths. Describe the hydrostatic bellows. Its law of equilibrium. What is the hydrostatic paradox? Give illustrations. Give the principle of fountains. How high will the water rise? How do modern engineers carry water across a river? Did the ancients understand this principle? Give the theory of the Artesian well, and of ordinary wells and springs.

91–2. Give the rule for finding the pressure on the bottom of a vessel. On the side. Define the water-level. Is the surface of water horizontal? If it were, what part of an approaching ship would we see first? Describe the spirit-level. Define specific gravity. What is the standard for solids and liquids? For gases? Explain the buoyant force of liquids.

93. What is Archimedes's law? (p. 119.) Describe the "cylinder-and-bucket experiment." What does it prove? Give the method of finding the specific gravity of a solid.

94–6. A liquid. Is it necessary to use a specific gravity flask holding just 1000 ozs. or would any size answer? Suppose the solid is lighter than water and will not sink, what can you do? Explain the hydrometer. How can you find the weight of a given bulk of any substance? The bulk of any given weight? The exact volume of a body? Illustrate the action of dense liquids on floating bodies. Why will an iron ship float on water? Where is the centre of gravity in a floating body? How do fish sink at pleasure?

2. HYDRAULICS.—Define. To what is the velocity of a jet equal? How is the velocity found? Give the rule for finding the quantity of water which can be discharged from a jet in a given time. What is the effect of tubes? Tell something of the flow of water in rivers.

99–102. Name and describe the different kinds of water-wheels. Which is the most valuable form? What is the principle of the Turbine? Describe Barker's Mill. How are waves produced? Explain the real motion of the water. How does the motion of the whole wave differ from that of each particle? How is the character of waves modified near the shore? What is the extreme height of "mountain waves?" Define like phases. Unlike phases. A wave-length. What is the effect if two waves with like phases coincide? With unlike phases? What is this termed?

3. PNEUMATICS.—Define. What principles are common to liquids and gases? What gas is taken as the type? Describe the air-pump. Can a perfect vacuum be obtained in this way? (See p. 118.) What is the condenser? Its use? Prove that the air has weight.

105. Show its elasticity and compressibility. Describe the bottle-imps. What principles do they illustrate? Show the expansibility of the air.

106–7. Describe the experiments with the hand-glass. The principle of Hero's fountain. The Magdeburg hemispheres. What do they prove? Show the upward pressure of the air.

108. The buoyant force of the air. Would a pound of feathers and a pound of lead balance, if placed in a vacuum? On what principle does a balloon rise? What is the amount of the pressure of the air? Describe the experiment illustrating this. Where do these figures apply?

109–110. Describe how the pressure of the air constantly varies. Explain Mariotte's (called also Boyle's) law. Describe the barometer. Its uses. Are the terms "fair," "foul," etc., often placed on the scale, to be relied upon? Why is mercury used for filling the barometer? Describe Otto Guericke's barometer.

111–113. Describe the action of the lifting-pump. The force-pump. The fire-engine. Compare the action of the lifting-pump with that of the air-pump. What is the siphon. Explain its theory.

114–16. Describe the pneumatic inkstand. The hydraulic ram. The atomizer. Show how a current of air drags with it the still atmosphere. What opposing forces act on the air? How high does the air extend? How does its density vary?

VI. **Acoustics.**—Define. Name and define the two senses of this word. May not the terms "light," "heat," etc., be used in the same way? Illustrate the formation of sound by vibrations.

124–5. Show how the sound of a tuning-fork is conveyed through the air. The report of a gun. The sound of a bell. The human voice. Define a sound-wave. In which direction do the molecules of air vibrate? In what form do the waves spread? Can a sound be made in a vacuum? Can a sound come to the earth from the stars?

126. How do sounds change as we pass above or below the sea-level? Upon what does the velocity of sound depend? Why is this? At what rate does sound travel in the air? In water? In the metals? In iron (p. 145)? What effect does temperature have on the velocity of sound?

127. Do all sounds travel at the same rate? How does the velocity of sound enable us to determine distance? Upon what does the in-

tensity of sound depend? At what rate does it diminish? Why? State wherein the laws of sound are similar to those of other phenomena. What does this uniformity prove?

128. Explain the speaking-tube. The ear-trumpet. Describe Biot's experiment in the water-pipes of Paris. The speaking-trumpet. What is the refraction of sound?

129–30. Define reflection of sound. What is the law? Give some curious instances of reflection (p. 145). What is the shape of a whispering-gallery? Illustrate the decrease of sound by repeated reflection. Why are sounds more distinct at night than by day? Is it desirable to have a door or a window behind a speaker? What causes the "ringing" of a sea-shell? How are echoes produced? When is the echo repeated? Illustrate the decrease of sound by reflection. What are acoustic clouds? *

* "The influence of wind on the intensity of sound seems due to the fact that, owing to obstructions opposed by the ground, there is a considerable difference between the velocity of the wind close to the ground and the velocity at the height of a few feet above the ground. Thus in a meadow the velocity of the wind at one foot above the surface may be only half what it is at eight feet above the surface. Let us take the velocity of sound at 1100 feet per second, and suppose that the velocity of a contrary wind is 10 feet per second at the surface, and 20 feet per second at the height of 8 feet above the surface. Thus, considering this circumstance alone, the wave of sound at the end of a second would be at the surface 10 feet in advance of its position at 8 feet above the surface; so that the front of the wave instead of being a vertical plane would be inclined to the horizon. Thus the sound instead of proceeding horizontally becomes turned upward. It only remains to add that this tilting of the front of the wave is not delayed until the end of a second, but begins at the origin of the sound and increases gradually. Hence a ray of sound, so to speak, instead of travelling horizontally is curved upwards, and thus passes over the head of a person stationed at a distance from the origin. A contrary wind then diminishes the intensity of sound by lifting the sound off the ground, and the amount of this lifting increases as the distance from the origin increases. The various consequences which may be deduced from the preceding theory have been verified by experiments. Thus it follows that a listener when the wind is contrary may expect to recover a sound, which he has lost at a certain distance from its origin, by ascending to some height above the surface. Also the influence of a wind will be but small if the surface be very smooth; thus sounds are heard against the wind much farther over calm water than over land. Again, suppose the origin of the sound to be elevated above the surface: then if the listener be also raised above the surface he may hear a very loud sound made up of two parts, namely, that which has travelled horizontally, and that which has been tilted upwards from the ground by the action of the contrary wind. Next, suppose the wind to be *favorable* instead of *contrary*. In this case the higher part of the wave of sound moves more rapidly than the lower, and so the plane front of the wave is tilted *forward*, and the rays of sound are bent *downward* to the advantage of the listener on the ground. Thus the influence of the wind on sound has been shown to depend on the circumstance that when the wind is blowing, the velocity of sound is different at different heights above the ground: similar effects will therefore follow if this difference of velocity is produced by any other cause instead of by the wind. Now change of temperature affects the velocity of sound: if the temperature rise one degree of Fahrenheit's thermometer the velocity increases by about a foot per second. In general, as we ascend in the air during the day the

131–3. What is the difference between noise and music? Upon what does pitch depend? Describe the siren. How is it used to determine the number of vibrations in a sound? How is the octave of any note produced? How can we ascertain the length of the wave in sound? What length of wave produces the low tones in music? The high tones? Give the illustration of the locomotive whistle.* When are two tones in unison? How can we find the length of the wave in *any* musical sound? What is meant by the super-position of sound-waves?

134. How can two sounds produce silence? What is this effect termed? Illustrate interference by means of a tuning-fork. What are "beats"? Describe the vibration of a cord.

135–7. Describe the sonometer. What is the object of the wooden box? Give the three laws of the vibration of cords. What is a node? Describe the experiments illustrating the formation of nodes. What are acoustic figures? Nodal lines?

138–140. What is the fundamental tone of a cord? A harmonic? What causes the difference in the sound of various instruments? Does a bell vibrate in nodes? The violin-case? A piano sounding-board? State the fractions representing the relative rates of vibration of the different notes of the scale. How is the sound produced in wind-instruments? How is the sound-wave started in an organ-pipe? In a flute? What determines the pitch? What are sympathetic vibrations? Describe the resonance globe. What is a sensitive flame?

141. A singing flame? Describe the phonograph. The ear. What is

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temperature decreases, and therefore so also does the velocity of sound. Thus the result is the same as in the case of a *contrary* wind; the ray of sound is lifted over the head of a person on the ground, so that the audibility of the sound is diminished. The presence of vapor in the atmosphere also affects the propagation of sound; the velocity increases as the quantity of vapor increases. The direct effect, however, is very slight, but indirectly the vapor is of consequence, for it gives to the air a greater power of radiating and absorbing heat, and so promotes inequality of temperature. The variation of temperature is greatest when the sun is shining, so that it is greater by day than by night, and greater in summer than in winter. Hence, according to the theory now explained, sounds ought to be heard more plainly by night than by day, and more plainly in winter than in summer. That sounds are heard more plainly by night than by day is a well-known fact. We have supposed that the temperature *decreases* as we ascend in the atmosphere; but it may happen on some occasion that the temperature at the surface is *lower* than it is a little above the surface. This may be the case for instance over the surface of the sea in the day time, and over the surface of the land by night. Thus the effect on sound will be similar to that of a *favorable* wind. It is obvious that by the combined influence of wind and temperature the results produced may vary much as to degree; for instance, the operation of a contrary wind may be neutralized by that of the temperature rising as we ascend above the surface." See Proceedings of the Royal Society of Great Britain, volumes XXII and XXIV.

* A speed of 40 miles per hour will sharpen the tone of the whistle of an approaching train by a semitone.

the object of the Eustachian tube? Is there any opening between the external and internal ear? What effect does it have on the hearing to increase or diminish the pressure of the air? How does a concussion sometimes cause temporary deafness? How can this be remedied? What are the limits of hearing? Does the range vary in different persons? What sounds are generally heard most acutely? Are there probably sounds in nature we never hear? Has nature a tendency to music? What causes the "whispering of the pines?" What is the key of nature?

VII. **Optics.**—Define. A luminous body. A non-luminous body. A medium. A transparent body. A translucent body. An opaque body. A ray of light. Show that neither air nor water is perfectly transparent. Why is the sun's light fainter at sunset than at mid-day? Define the visual angle. Show how distance and size are intimately related.

150. State the laws of light. Do they resemble those of sound? What is the velocity of light? How is this proved? Explain the undulatory theory of light.

151. How does light-motion differ from sound-motion? What is diffused light? Why are some objects brilliant and others dull? Why can we see a rough surface at any angle, and an image in the mirror at only a particular one? Would a perfectly smooth mirror be visible? How does reflection vary? Define mirrors. Name and define the three kinds.

152. What is the general principle of mirrors? Why is an image in a plane mirror symmetrical? Why is it reversed right and left? Why is it as far behind the mirror as the object is before it?

153–6. Why can we often see in a mirror several images of an object? Why can we see these best if we look into the mirror very obliquely? Why is an image seen in water inverted? When the moon is near the meridian, why can we see the image in the water at only one spot? When do we see a tremulous line of light? What is the action of a concave mirror on rays of light? Define the focus. Centre of curvature. Focal distance. Describe the image seen in a concave mirror. What are conjugate foci? Describe the image seen in a convex mirror. Why is it smaller than life? Why can it not be inverted like one seen in a concave mirror? Define total reflection.

157. Define Refraction. Does the partial reflection of light as it passes from one medium to another of different density have a parallel in sound? Why is powdered ice opaque while a block of ice is transparent? Give illustrations of refraction.

158. Why does an object in water appear to be above its true place? What is the general principle of refraction? State the laws of refrac-

tion. Describe the path of a ray through a window-glass. Is the direction of objects changed? Describe the path through a prism.

159–61. Name and describe the different kinds of lenses. What is the effect of a double-convex lens on rays of light? What is this kind of lens often called? Describe the image. Why is it inverted after we pass the principal focus? Why is it decreased in size? What is the effect of a double-concave lens on rays of light? Describe the image. Why can it not be inverted like one through a double-convex lens? Describe the images seen in the large vases in the windows of drug-stores. What is Aberration? *

162. What is a mirage? Give its cause.

163. How is the solar spectrum formed? Name the seven primary colors. Show that these seven will form white light. Why are the rays separated? What is meant by the dispersive power of a prism? What apparatus possesses this property in a high degree? *Ans.* A triangular bottle filled with a liquid called carbon disulphide (*Chemistry*, p. 118). What three classes of rays compose the spectrum? Do artificial lights differ in their proportion of these rays? Why does the window of a photographer's dark room sometimes contain yellow glass?

164–7. Describe the three kinds of spectra. The spectroscope. What are its uses? Describe rainbows—primary and secondary. Why is the rainbow circular? How is the rainbow formed? Why must it rain and the sun shine at the same time, to produce the bow? Why is the bow in the sky opposite the sun? How many refractions and reflections form the primary bow? The secondary? How many colors can one receive from a single drop? Define complementary colors. How can they be seen? What is the effect of complementary colors

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* To prevent spherical aberration the pupil of the eye can be made very small. The photographer reaches the same result by the use of a diaphragm with a small aperture. "The power of a small orifice to correct the greatest amount of distortion from interfering rays is shown by a simple experiment. The normal eye of an adult cannot see to read small print nearer than six inches. Within that distance the type becomes more indistinct the closer it approaches the eye. But if we make a pinhole through a card and place it close to the eye, we can see to read printed matter of any size even as near as half an inch from the eye. At that distance we can see even the texture of fine cambric with microscopic definition. The cause of this is easily explicable. The rays striking the lens perpendicularly on the centre suffer no refraction. The effect of the pinhole is to exclude all rays but those that impinge perpendicularly on the centre of the eye lenses. Hence the image of the object close in front of the eye is pictured on the retina without the interference of the surrounding rays, which would fall obliquely on the lens, and being refracted out of focus would blur the picture. Observation of the effect of a small orifice in correcting aberrant rays, and of the fact that the pupil contracts in near vision, led Haller and some other physiologists to believe that contraction of the pupil was the sole factor in near accommodation. But this view has been sufficiently refuted by other observers."—*Dr. Dudgeon's "Human Eye,"* p. 76.

when brought in contrast? (In Fig. 163 opposite colors are complementary.) Why do colors seen by artificial light appear differently than by day-light—as yellow seems white, blue turns to green, etc.

168. Describe Newton's rings. How are these explained according to the wave theory? What causes the play of color in mother-of-pearl? In soap-bubbles? In the scum on stagnant water? In thin layers of mica or quartz?

169. What can you say about the length of the waves? State the analogy between color and pitch in music. Why is grass green? When is a body white? Black? What is color-blindness?

170. What is double refraction? What are the two rays termed? What is polarized light? How does a dot appear through Iceland spar? What other methods are there of polarizing light? State some illustrations and practical uses of polarized light.

171. What is the meaning of the word microscope? Describe the simple microscope. The compound microscope. How is the power of a microscope indicated? Do we see the object directly in a microscope? Why is the object-lens made so small and so convex?

172–3. What is the meaning of the word telescope? Describe the reflecting telescope. The refracting telescope, What is the use of the object-lens? The eye-piece? Is the image inverted? Describe the opera-glass.

174. The stereoscope. The magic lantern. How are dissolving views produced?

175–7. Describe the Camera. The structure of the eye.* The formation of an image on the retina. The adjustment of the eye. The cause of near and far sightedness. The remedy. Why do old people hold a book at arm's length? Illustrate the duration of an impression. What is the range of the eye?

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* "In the skate's eye, and generally in the eyes of fishes, the cornea is nearly quite flat, the aqueous humor is insignificant, and there is virtually no anterior chamber, for the crystalline lens comes up close to the cornea. A convex cornea filled by an aqueous humor would be of no use in the water, the refractive index of the water being identical with that of the aqueous humor. Accordingly the refraction of the rays of light has to be effected entirely by the crystalline lens, which is nearly spherical, and of much greater refractive power than the corresponding organ in animals which pass their lives in the air. The crystalline lens being so nearly spherical in shape and of such high refractive power, the axis of the eye is short. The eye of the turtle which is so much in the water, is very similar to that of the fish. The crystalline lens is very near the cornea. The lens is smaller proportionally than that of the skate, nor is it nearly so spherical; and its density, and consequently its refractive power, is somewhat less. Hence it has proportionally a longer focus. The cornea is more convex than that of the skate. The fish having no eyelids nor any lachrymal apparatus, its cornea will be apt to become dim by exposure to the air, but the turtle is well supplied with the requisite apparatus for maintaining the transparency of the eye in air. Ophidian reptiles have no eyelids or lachrymal apparatus, but they do not require them, as their cornea is transparent though dry."—*Dr. Dudgeon's "Human Eye,"* p. 50.

VIII. Heat.—Define luminous heat. Obscure heat. A diathermanous body. (See p. 205.) Cold. Gases and vapors. Show the intimate relation between light and heat. What is light? How do the three classes of rays in the solar spectrum differ? What effect does each of these produce? What is the theory of heat? Why can we not see with our fingers or taste with our ears? At what rate does nerve-motion travel? (See *Physiology*, p. 159.) How long does it take a tall man to find out what is going on in his foot?

185–7. Name the sources of heat. Describe and illustrate each of these. Can force be destroyed? If apparently lost, what becomes of it? What is Joule's law? Define latent, sensible, and specific heat. Explain the paradox, "that freezing is a warming process and thawing a cooling one." Why does "heat expand and cold contract"? What do you say as to the expansion of solids, liquids, and gases? Illustrate the expansion of solids. Is it better to buy alcohol in summer or in winter? What is the thermometer? Describe it. Describe the process of filling and grading. The F., C., and R. scales. Tell what you can about liquefaction. Of a solid. Of a gas. In one case sensible heat becomes latent, in the other latent heat becomes sensible—why is this?

188–90. Explain how a freezing mixture "makes ice-cream." State the theory of vaporization. Of distillation. Since rain comes from the ocean, why is it not salt? Describe the theory of boiling. What is the boiling point? Do all liquids boil at the same temperature? What would be the effect, if this were the case? Upon what does the boiling-point depend? Why does pressure raise the melt. pt. of most substances but lessen that of ice (See notes, pp. 190 and 202)? Why does salt-water boil at a higher temperature than fresh-water? Why will milk boil over so easily? Why will soup keep hot longer than boiling water? Does the air, dissolved in water, have any influence on the boiling-point? (p. 202.) Can you measure the height of a mountain by means of a tea-kettle and a thermometer? Show how cold water may be used to make warm water boil? At what temperature will water boil in a vacuum? Why? Can we heat water in the open air above the boiling-point? What becomes of the extra heat? What is the latent heat of water? Upon what principle are buildings heated by steam? Have you ever seen any steam?

191. Define evaporation. Does snow evaporate in the winter? What can be done to hasten evaporation? Why is a saucepan made broad? Why do we cool ourselves by fanning? Why does an application of spirits to the forehead allay fever? Why does wind hasten the drying of clothes? Describe a vacuum-pan. Why is evaporation hastened in a vacuum? Why is evaporation a cooling process? How is ice manufactured in the tropics? What is the spheroidal state?

192–3. Name and define the three modes of communicating heat.

Give illustrations showing the relative conducting power of solids, liquids, and gases. What substances are the best conductors? Is water a good conductor? Air? What is the principle of ice-houses? Fire-proof safes? Why do not flannel and marble appear to be of the same temperature? Is ice always of the same temperature? Describe the convective currents in heating water. Where must the heat be applied? Where should ice be applied in order to cool water? Describe the convective currents in heating air. Upon what principle are hot-air furnaces constructed? Ought the ventilator at the top of a room to be opened in winter? At the bottom? Is space warmed by the sunbeam?

194. Does the heat of the sun come in through our windows? Does the heat of our stoves pass out in the same way? Show how the vapor in the air helps to keep the earth warm. Explain the Radiometer. The relation between absorption and reflection.

195. What is the elastic force of steam at the ordinary pressure of the air? What is the difference between a high-pressure and a low-pressure engine? Which is used for a locomotive? Why? Describe the governor. What is the object of a fly-wheel?

197. How does the capacity of the air for moisture vary? What is the principle on which dew, rain, etc., depend? Show that a change in density produces a change in temperature. What effect does this have on the temperature of elevated regions? Does an ounce of air on a mountain-top contain the same quantity of heat as the same weight at the foot? How is dew formed?

198–9. Upon what objects will it collect most readily? Why will it not form on windy nights? Why is rice-straw used in Bengal in making ice? What is a fog? Why do fogs form over ponds in the early evening? Cause of fogs over the Newfoundland banks? How does a fog differ from a cloud? Why do clouds remain suspended in the air, contrary to gravity? Describe the different kinds of clouds. Describe the formation of rain. Snow.

200–3. How are winds produced? Land-and-sea breezes? Trade-winds? Oceanic currents? Tell about the Gulf Stream. Explain the influence which water has on climate. Of what practical use is the air in water? Describe the exception which exists in the freezing of water. Why is this made? Describe the two processes by which pure water can be obtained. How is an excessive deposit of dew prevented?

IX. **Electricity.**—Give the origin of this word. Name the different kinds of Electricity. Define Magnetism. A Magnet. A natural magnet. An artificial one. A bar-magnet. A horse-shoe magnet. The poles. The magnetic curves. Describe a magnetic needle. What

is the law of magnetic attraction and repulsion? Define magnetic induction. Explain it.

213. When is a body polarized? Give some illustrations of induced magnetism. Does a magnet lose any force by induction? How do you explain the fact that if you break a magnet each part will have its N. and S. poles.

214–15. Describe the process of making a magnet. On what principle will you explain this? Describe the compass. Is the needle true to the pole? What causes it to vary? What is the line of no variation? Declination? Why does the needle point N. and S.? What is a dipping-needle? Explain. How is a needle balanced?

216–17. Where is the N. magnetic pole? How would one know when he reached it? Does the earth induce magnetism? Which end of an upright bar will be the S. pole? How has the loadstone become polarized? Define frictional electricity. The electroscope. Difference between static and dynamic electricity. Show the existence of two kinds of electricity. Give the names applied to each.

219. State the law. What is the theory of electricity? Is it a polar force? Is it easily disturbed? Define a conductor. An insulator.

220–3. What is the best conductor? Best insulator? Is a poor conductor a good insulator? When is a body said to be insulated? Can electricity be collected from an iron rod? Describe a plate-glass electrical-machine. What is the use of the chain at the negative pole? Describe Holtz's electrical machine. Define electrical induction. State Faraday's theory.

224–5. What is the relation between induction and attraction and repulsion? Describe the electric chime. Explain. Describe the dancing images. The Leyden jar. What gives the color to the spark? How is the jar discharged?

226–7. What are the essentials of a Leyden jar? What is the object of the glass? The tinfoil? State the theory of the charging of the jar. Can an insulated jar be charged? Is the electricity on the surface or in the glass? Can the inner molecules of a solid conductor be charged? Will a rod contain any more electricity than a tube? Why is the prime conductor of an electrical-machine hollow? What is the effect of points? Describe the electric whirl. Explain the existence of electricity in the atmosphere. What is the cause of lightning? Thunder? Is there any danger when you once hear the report? Describe the different kinds of lightning. Tell how Franklin discovered the identity of lightning and frictional electricity. (See p. 251.)

228–9. What is the cause of the Aurora Borealis? How is this shown? Prove the intimate relation between the aurora and magnetism. Tell what you can about lightning rods. In what consists the main value of the rod? Does the lightning ever pass upward

from the earth? *Ans.* It does, both quietly and by sudden discharge. Has Nature provided any lightning-rods? What is St. Elmo's fire? What is the velocity of electricity? Illustrate its instantaneousness.

230–1. Name some of the effects of frictional electricity—(1) Physical, (2) Chemical, (3) Physiological. How are galvanic electricity and chemistry related? Why is galvanic or voltaic electricity thus named? Tell the story of Galvani's discovery. (See p. 251.) What was his theory? Give an account of Volta's discovery. How can we form a simple pile? Describe the simple galvanic circuit.

232. Define the poles. Electrodes. Closing and breaking the circuit. What is necessary to form a voltaic pair? Are the terms applied to the metals the same as those to the poles? Describe the chemical change. Why does the hydrogen come off from the copper? Tell what you can about the current.

233. What really passes along the wire? How is this force transmitted? Will a tube, then, *convey* as much electricity as a rod? Explain the term electric potential.

234–5. Describe Smee's battery. Grove's battery. The chemical change in this battery. What are the advantages of Grove's battery? Describe Bunsen's battery. Daniell's battery. The sulphate of copper battery. Define quantity and intensity. Upon what do they depend? Compare frictional and galvanic electricity.

236–9. State the effects of galvanic electricity, (1) Physical—heat and light; (2) Chemical—decomposition of water, electrolysis, electrotyping, electro-plating, etc.; (3) Physiological.

240. What is the effect of a voltaic current on a magnetic needle? What is a galvanometer? An astatic needle? An electro-magnet? A helix? Show how a helix can be magnetized. How are bar-magnets made? How is motion produced by electricity? Describe Page's rotating-machine. What is the principle of an electric engine? What difficulty is there in its practical use? Describe the magnetic telegraph. How is a message sent? How is one received? What is a sounder? What is the general principle of the telegraph? Describe the relay. Name the use of each instrument. Define magnetic electricity. Describe a magneto-electric machine. Describe Wild's machine. What are induced currents? Describe the Telephone. The Microphone. What is the difference between the acoustic and the magnetic telephone? Explain Ruhmkorff's coil. Thermal electricity. A thermo-electric pile. Describe the electric fish.

TABLES.

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I. LAWS OF FALLING BODIES.

			Feet.	In terms of 16 feet.
Velocity at end of	1st	second	= 32	= 32 = 2 × 16.
" " "	2d	"	= 32 + 32	= 64 = 4 × 16.
" " "	3d	"	= 32 + 32 + 32	= 96 = 6 × 16.

The constant increase given by gravity for every second is 32 feet.

Distance for any second equals the mean between velocity at the beginning and velocity at the end of that second.

$$\therefore \quad s = \frac{v \text{ at beginning} + v \text{ at end}}{2}.$$

Hence,

$$\text{Distance for 1st second} = \frac{0 + 32}{2} = 16 = 1 \times 16.$$

$$\text{" " 2d "} = \frac{32 + 64}{2} = 48 = 3 \times 16.$$

$$\text{" " 3d "} = \frac{64 + 96}{2} = 80 = 5 \times 16.$$

II. ANALYSIS OF THE MOTION OF A FALLING BODY.

1st sec.	1 space. Acquired velocity = 2 spaces.	
2d sec.	3 spaces. Acquired velocity = 4 spaces.	
3d sec.	5 spaces. Acquired velocity = 6 spaces.	
4th sec.	7 spaces. Acquired velocity = 8 spaces.	

1 space = 16 ft.

Acquired velocity is such as would carry the body over *twice* the space already passed in *same length of time*, without farther aid from gravity. Since gravity *does aid it*, however, to the extent of 16 ft. a second, we must include its aid in calculating the entire space passed over. Ex.: At the end of 3 seconds the body has passed over 1 + 3 + 5 = 9 spaces. Twice this = 18 spaces for the 3 seconds, or 6 spaces for one second. These 6 spaces will be utilized during the next (4th) second, and, in addition, gravity will furnish one space, making 7 spaces through which the body will move during the 4th second.

III. SECOND LAW OF PENDULUMS.

Time of vibration = 1 second. = 2 seconds. = 3 seconds.

Length = 39.1 in.

Length = 4 × 39.1 in.

Length = 9 × 39.1 in.

BLACKBOARD DRAWINGS.

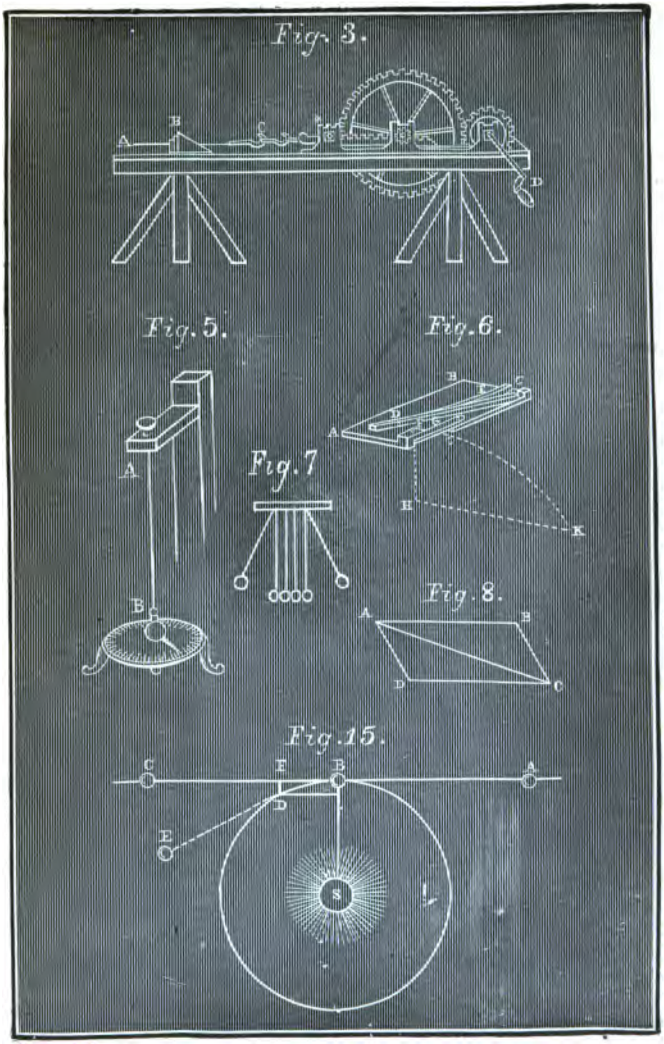

Fig. 3.—*Wire-drawing Machine.*
Fig. 5.—*Torsion Balance.*
Fig. 6.—*Simultaneous Forces.*
Fig. 7.—*Reaction Balls.*
Fig. 8.—*Compound Motion.*
Fig 15.—*Earth's Motion.*

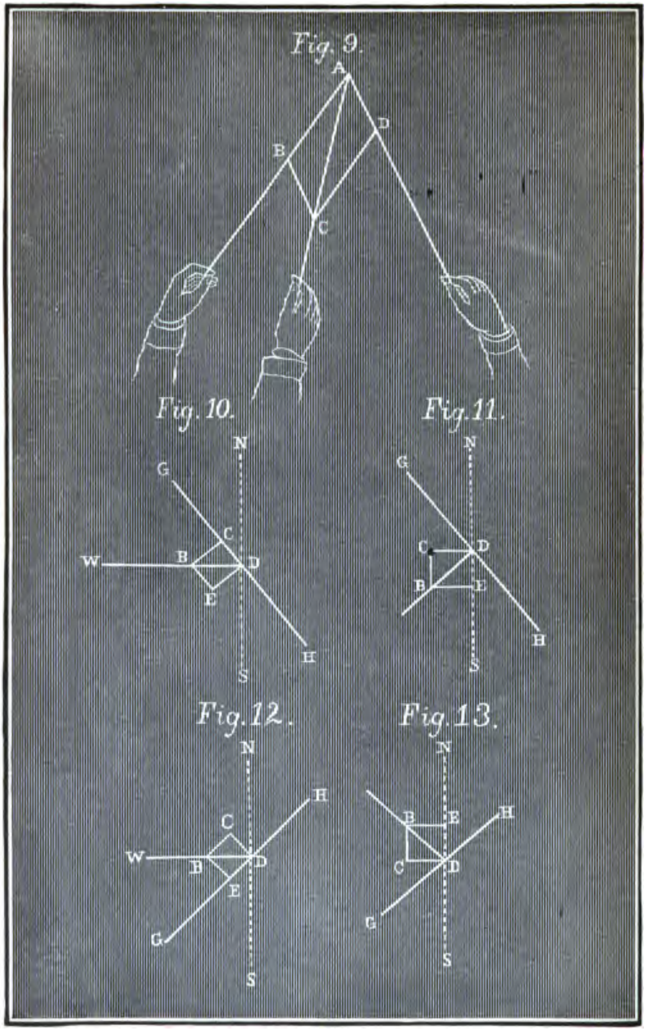

Fig. 9.—Parallelogram of Forces.

Figs. 10 to 13.—Resolution of Forces.

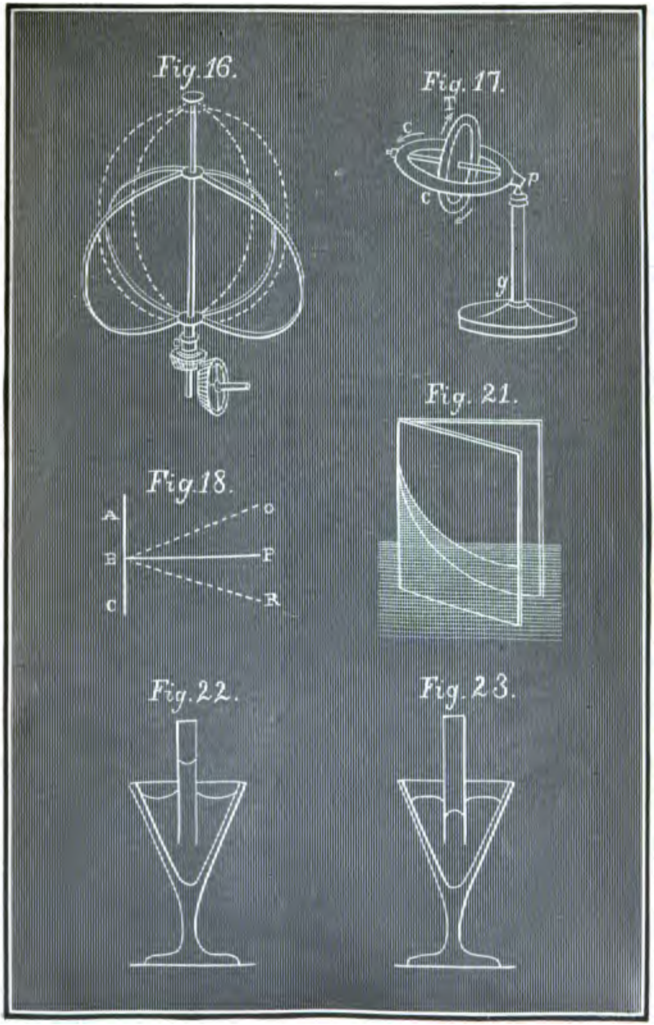

Fig. 16.—Centrifugal Force.
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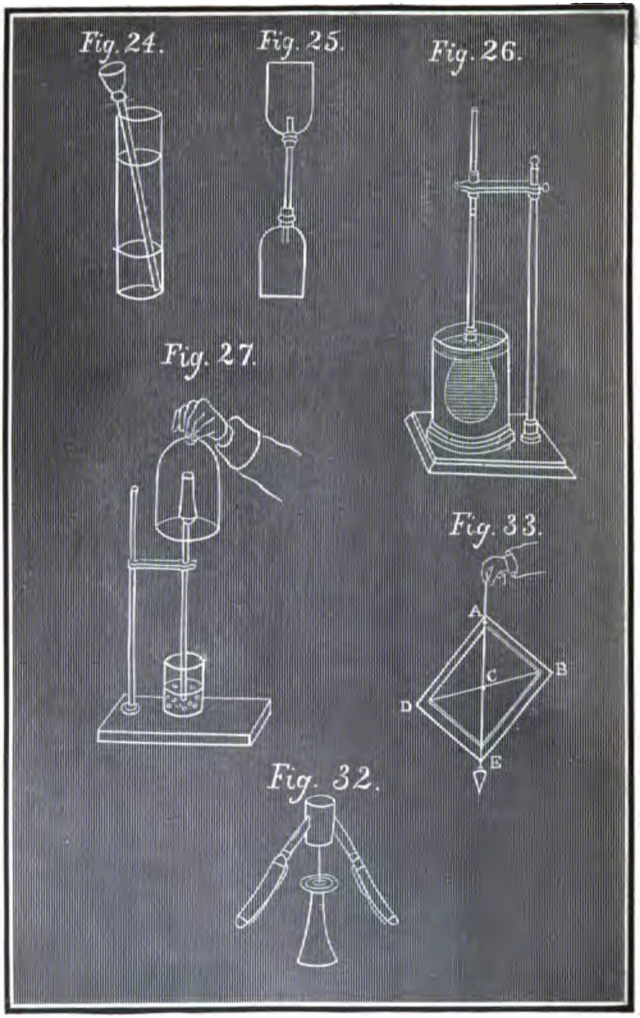

Fig. 24.—*Diffusion of Liquids.*
Fig. 25.—*Diffusion of Gases.*
Fig. 26.—*Osmose of Liquids.*
Fig. 27.—*Osmose of Gases.*
Fig. 32.—*Stable Equilibrium.*
Fig. 33.—*To find Centre of Gravity.*

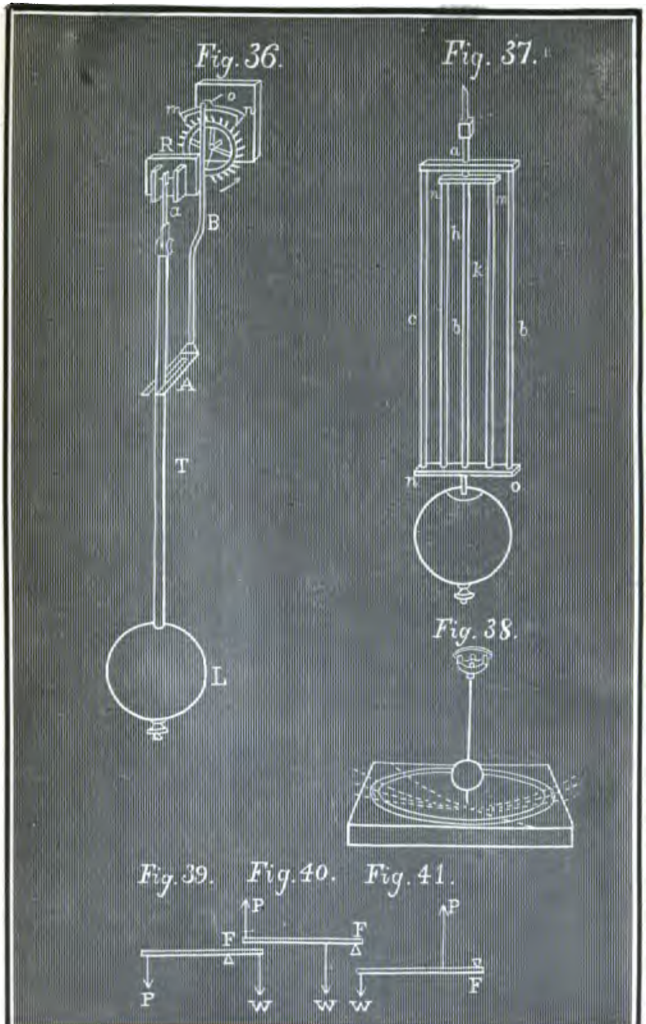

Fig. 36.—*Clock Pendulum.*
Fig. 37.—*Gridiron Pendulum.*
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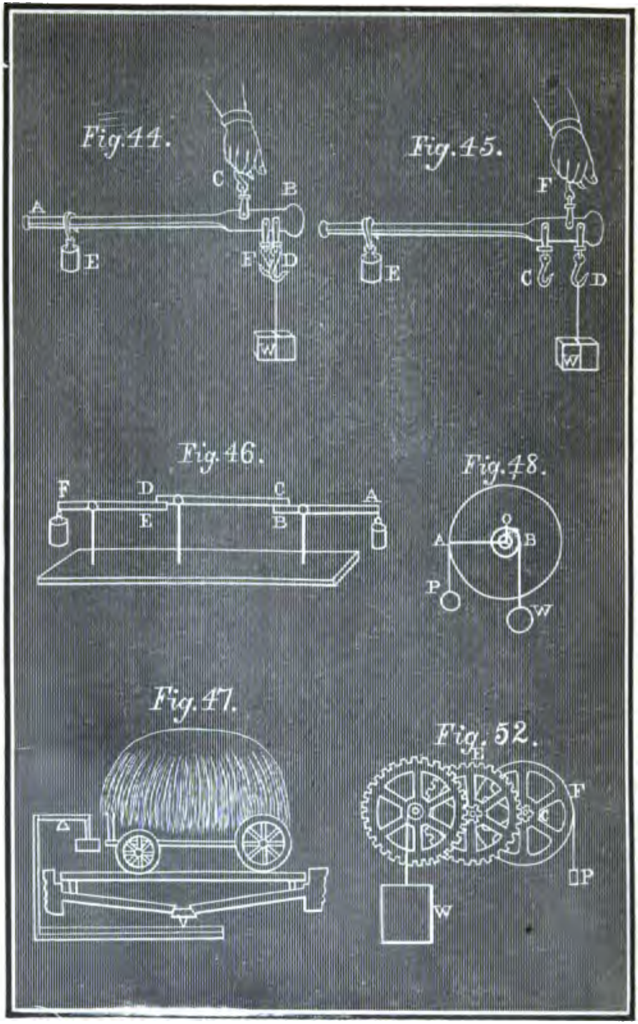

Figs. 44 *and* 45.—*The Steelyard.*
Fig. 46.—*Compound Lever.*
Fig. 47.—*Hay-scales.*
Fig. 48.—*Wheel and Axle.*
Fig. 52.—*Wheelwork.*

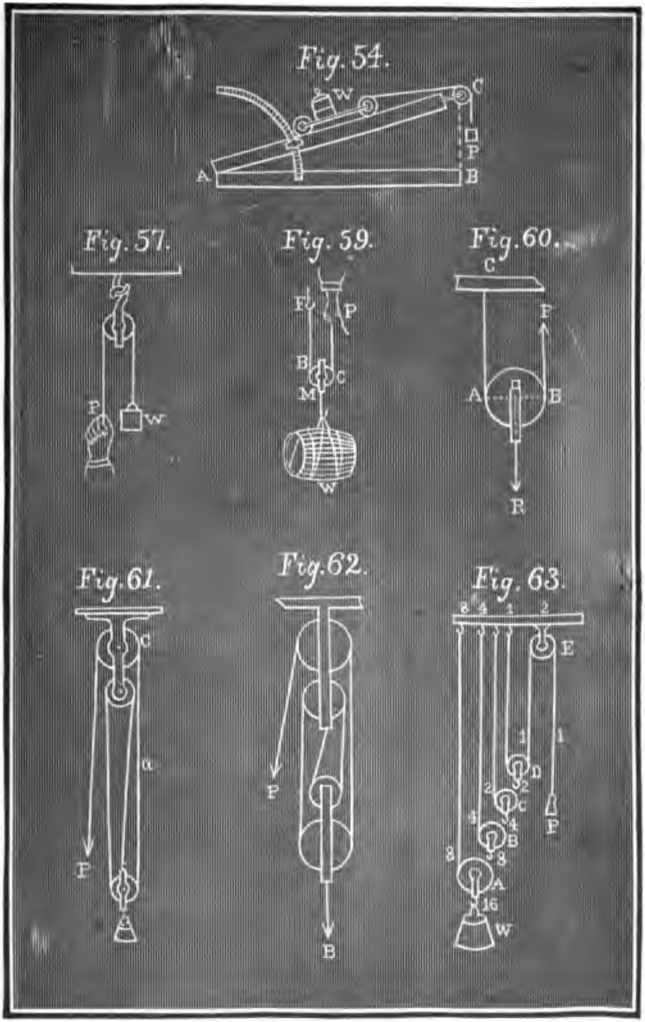

Fig. 54.—*Inclined Plane.*
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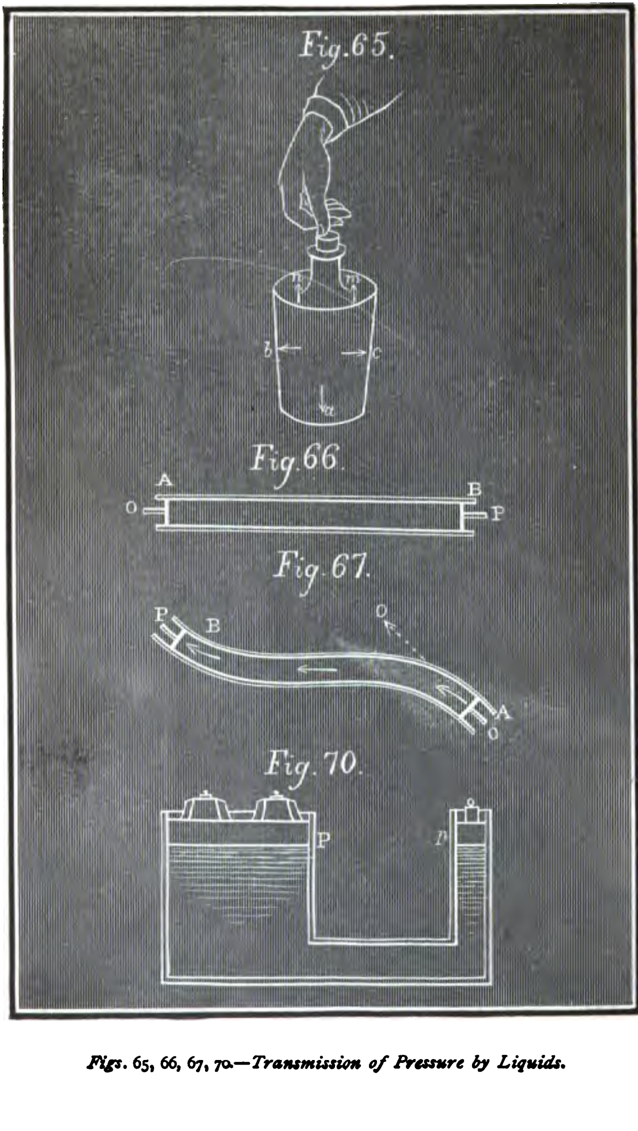

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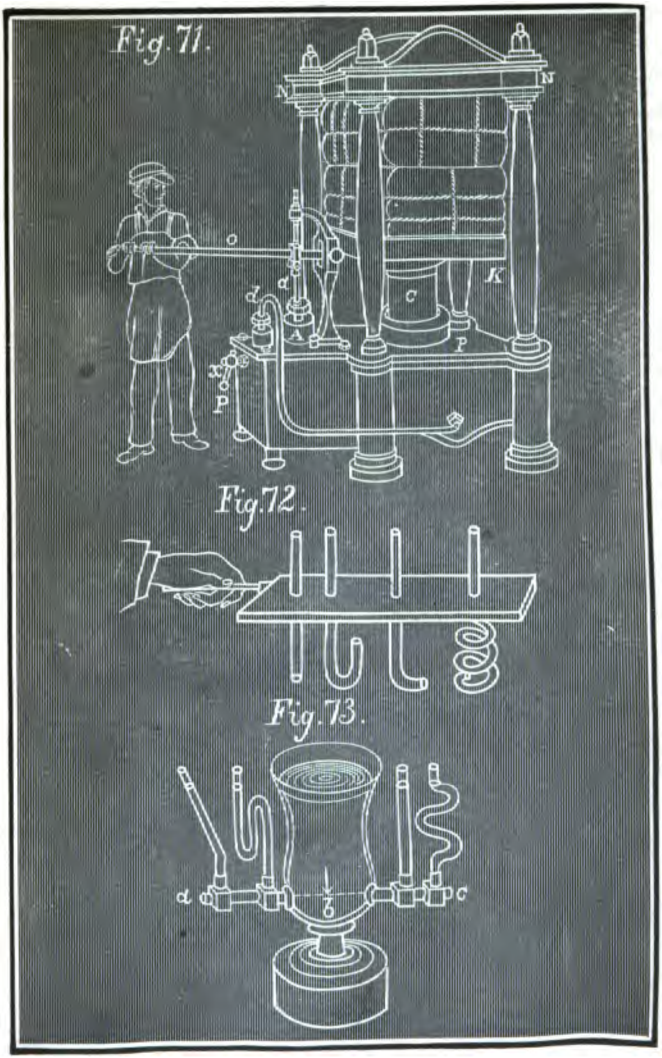

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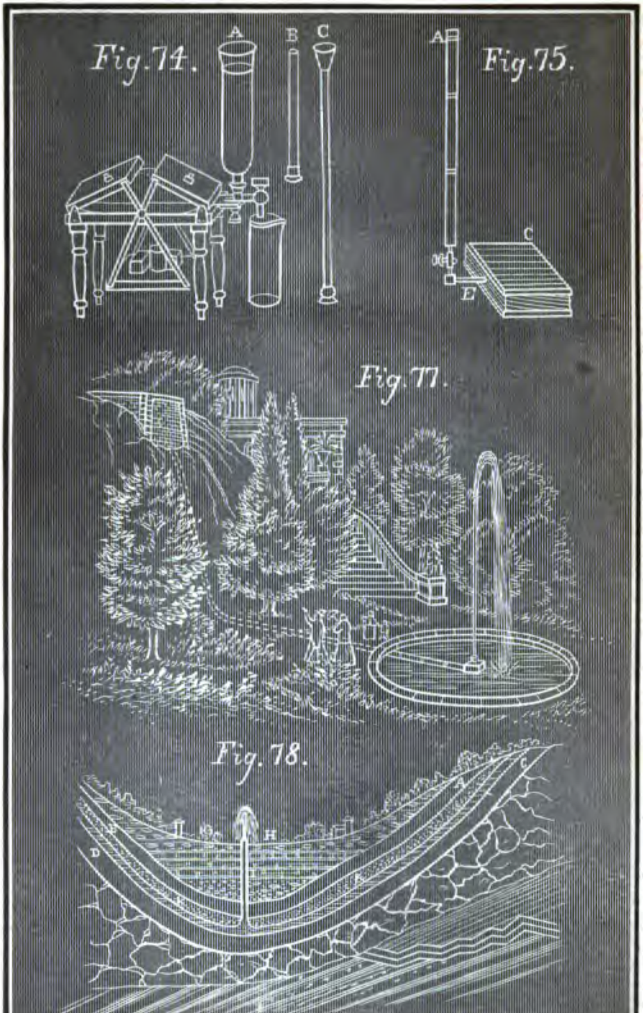

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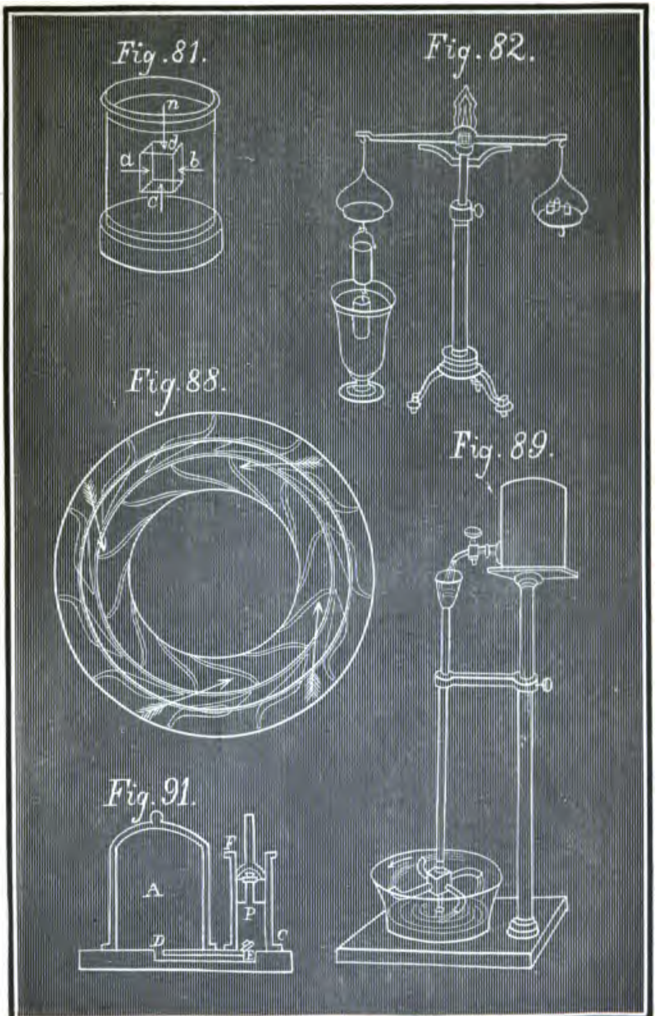

Fig. 81.—*Buoyant Force of Liquids.*
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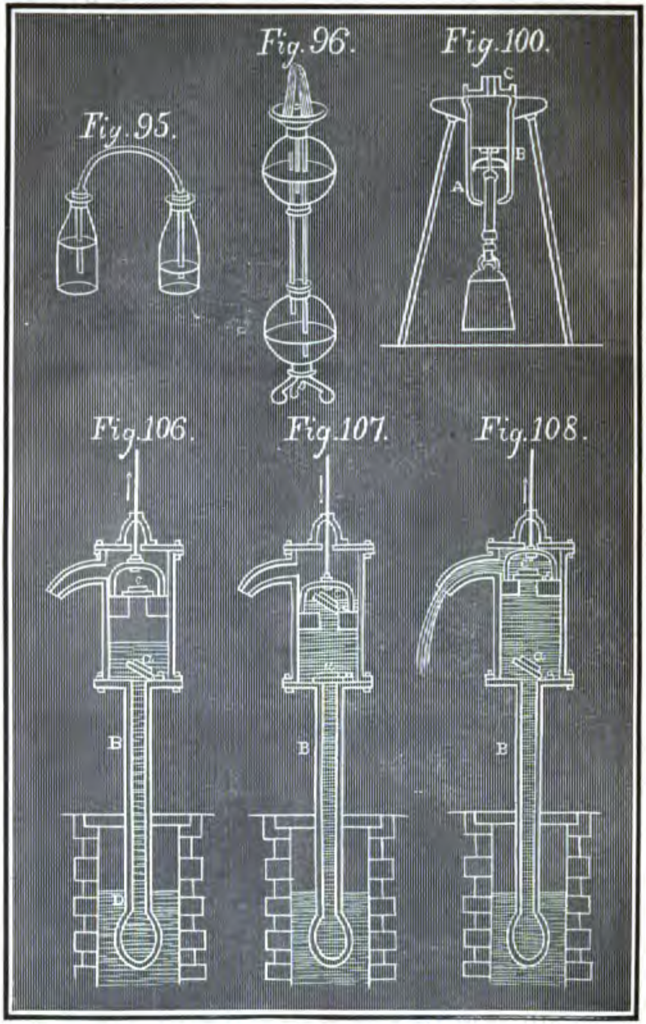

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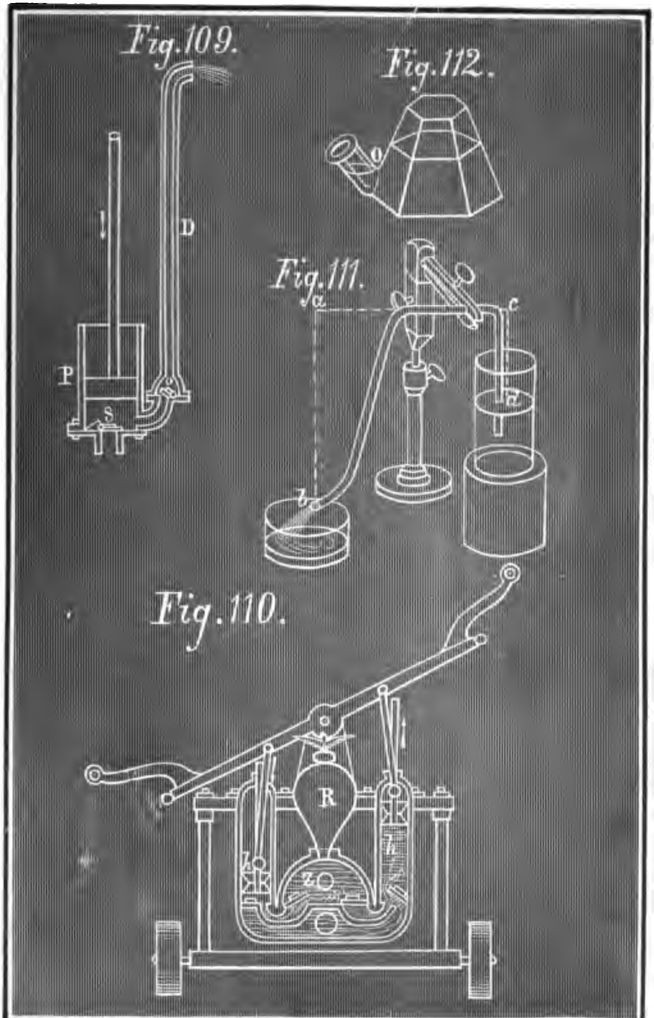

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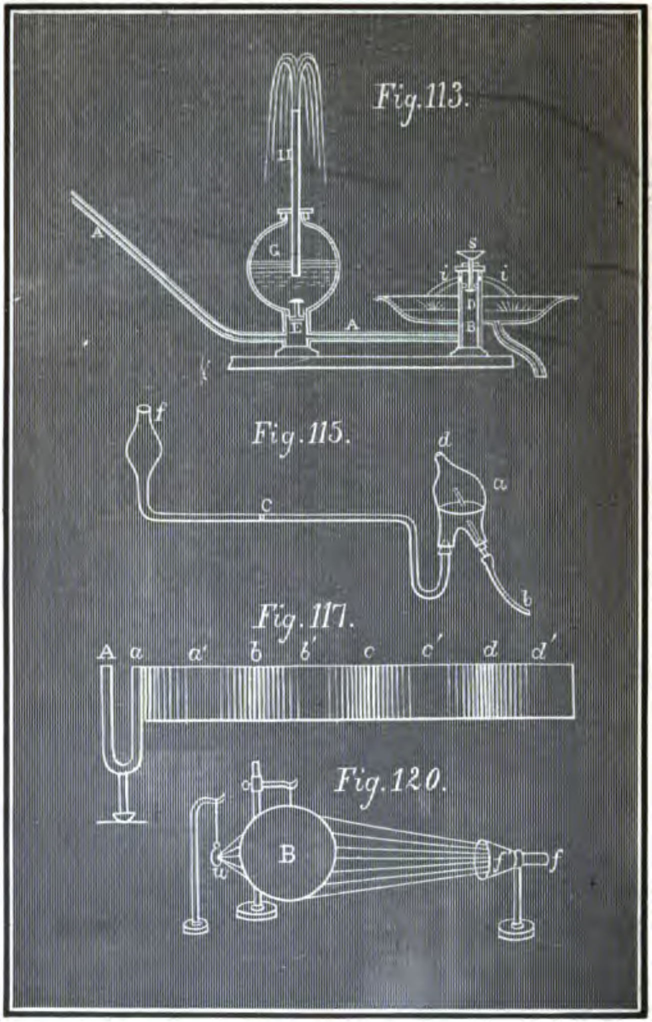

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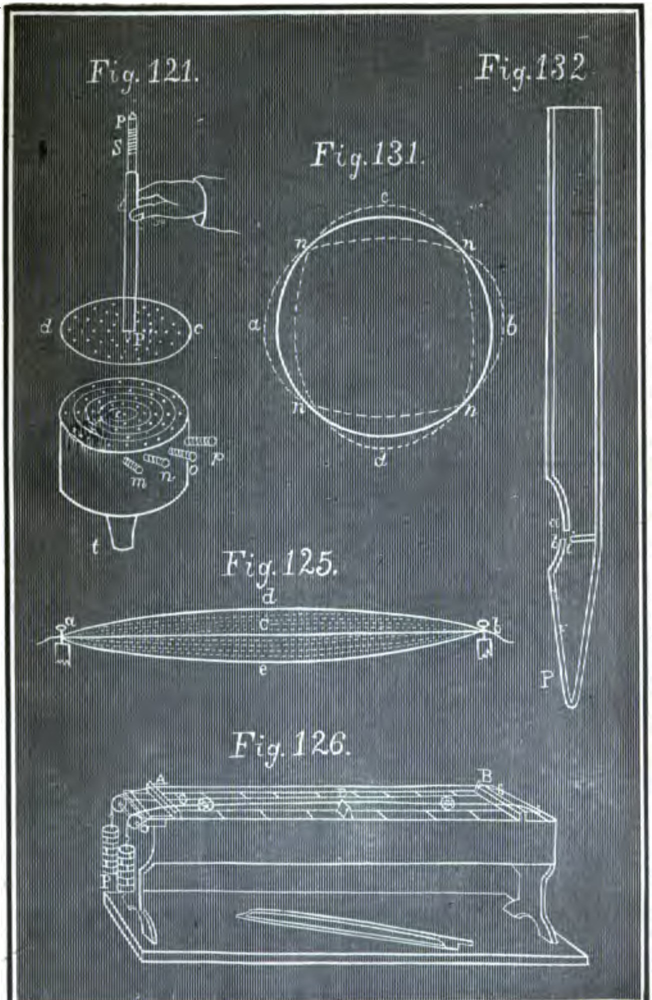

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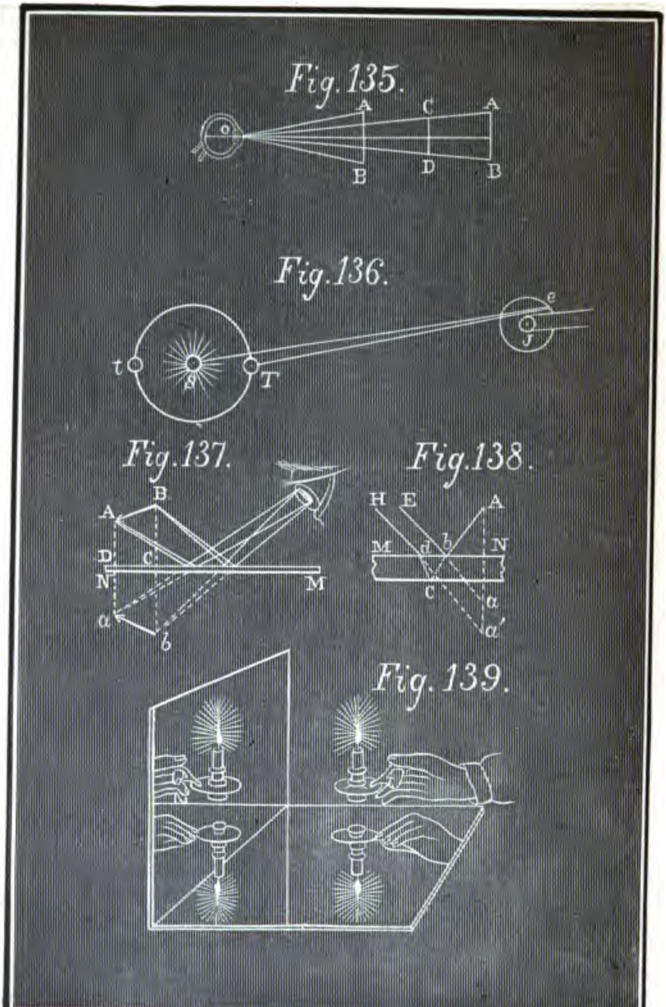

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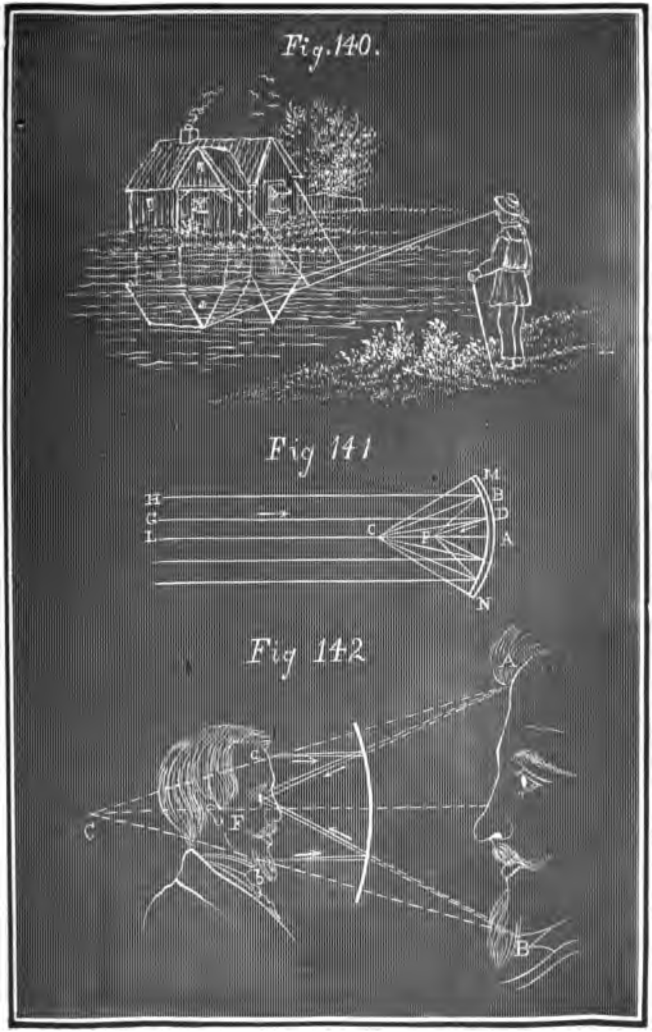

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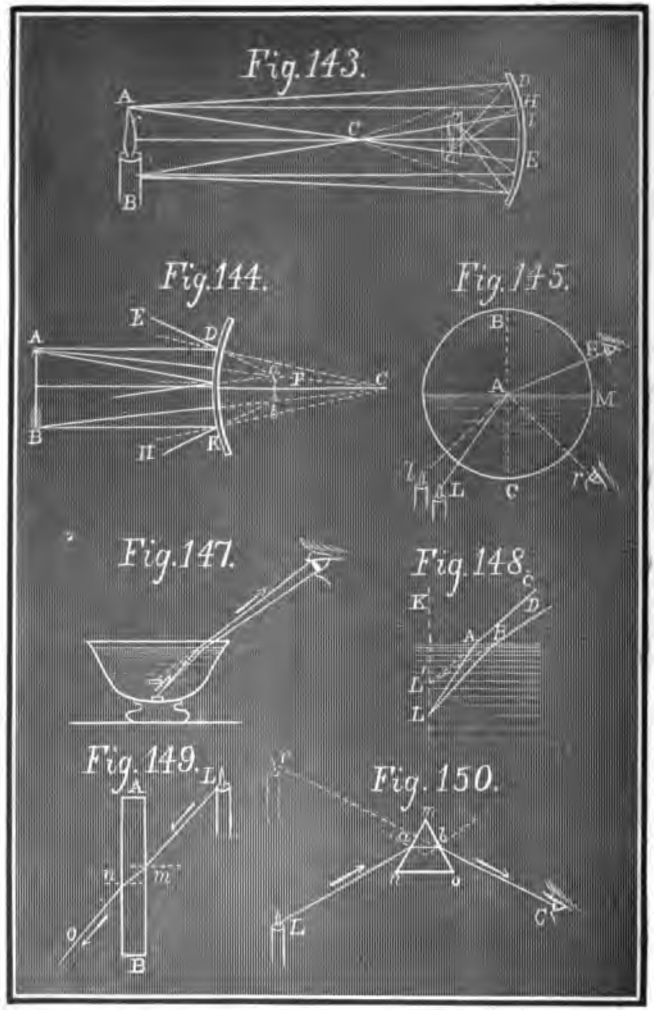

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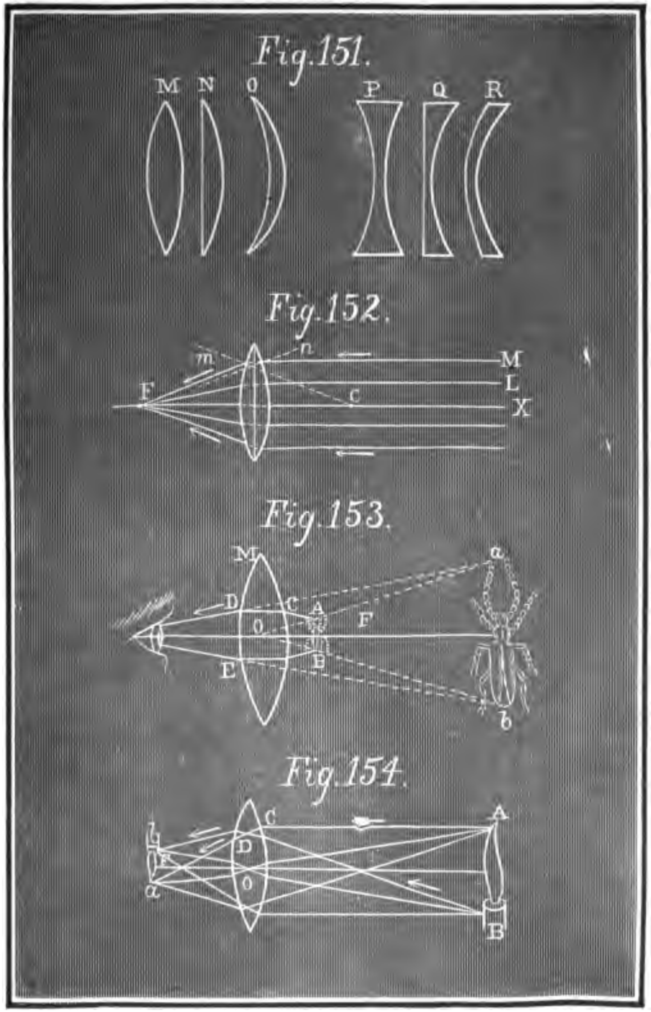

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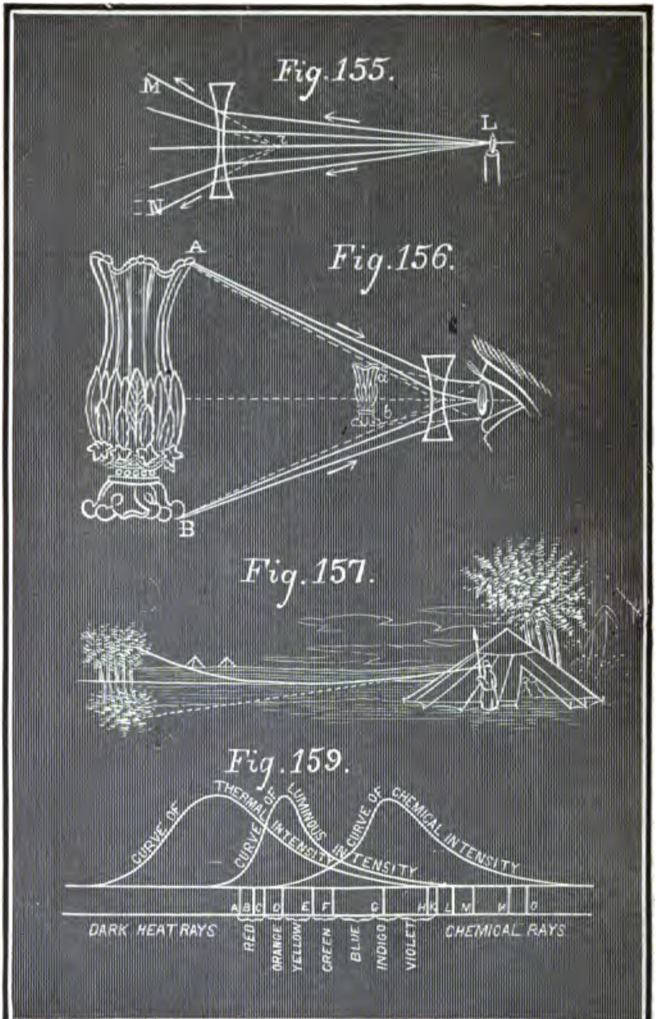

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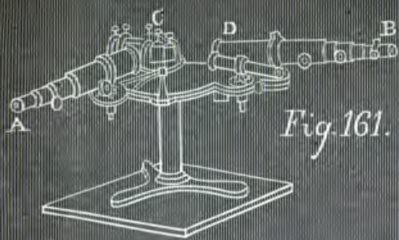

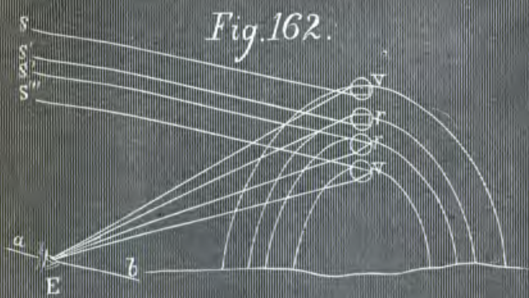

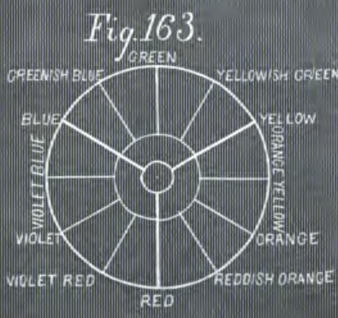

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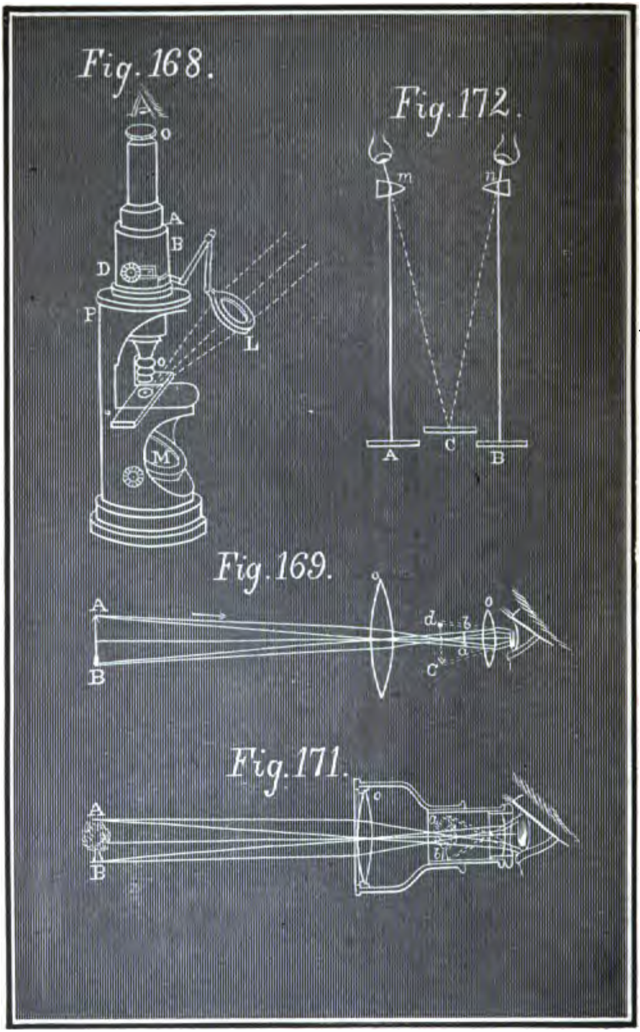

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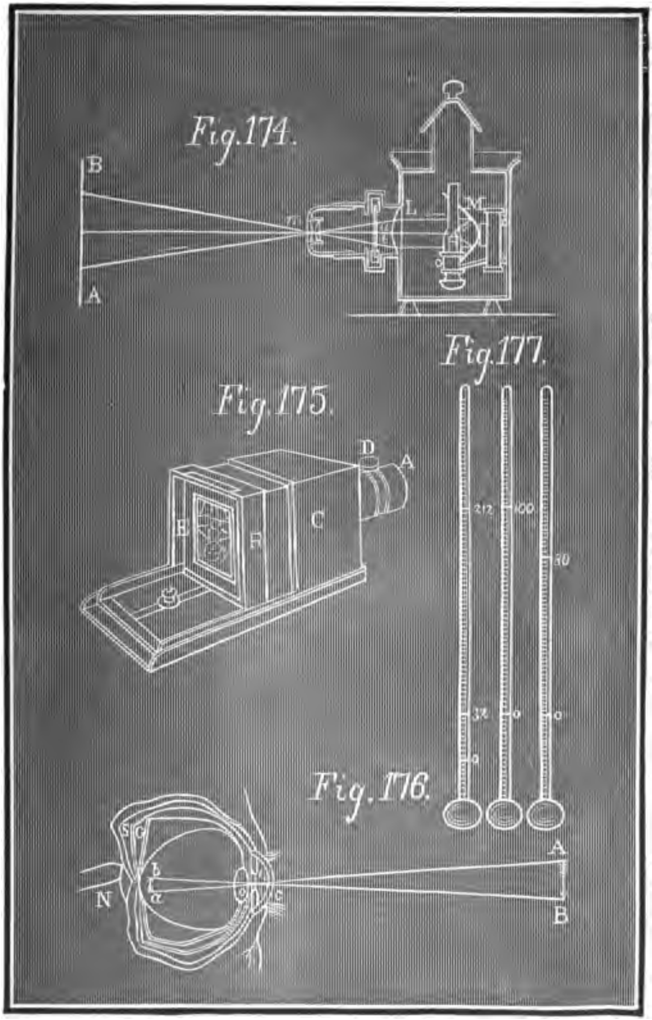

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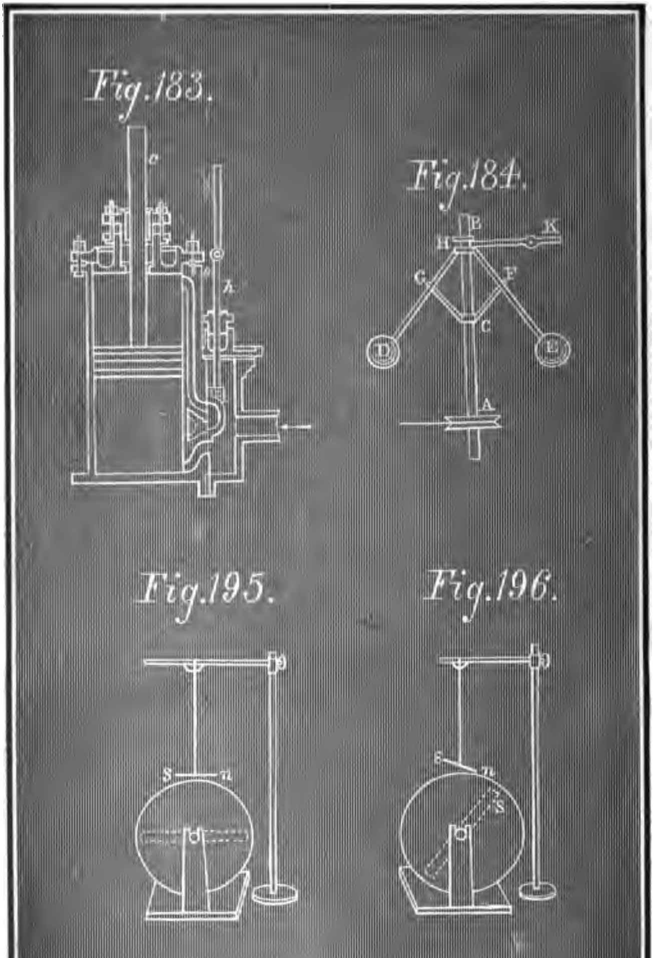

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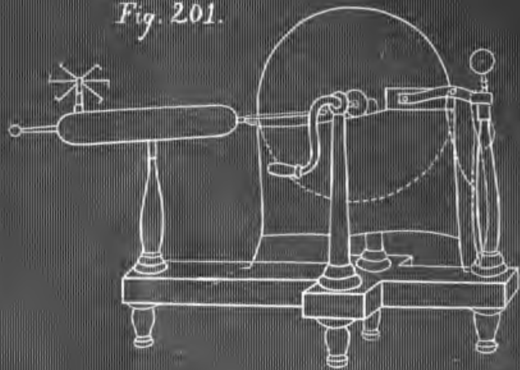

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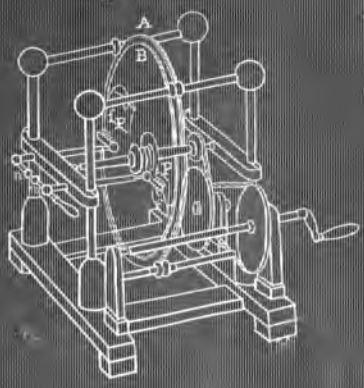

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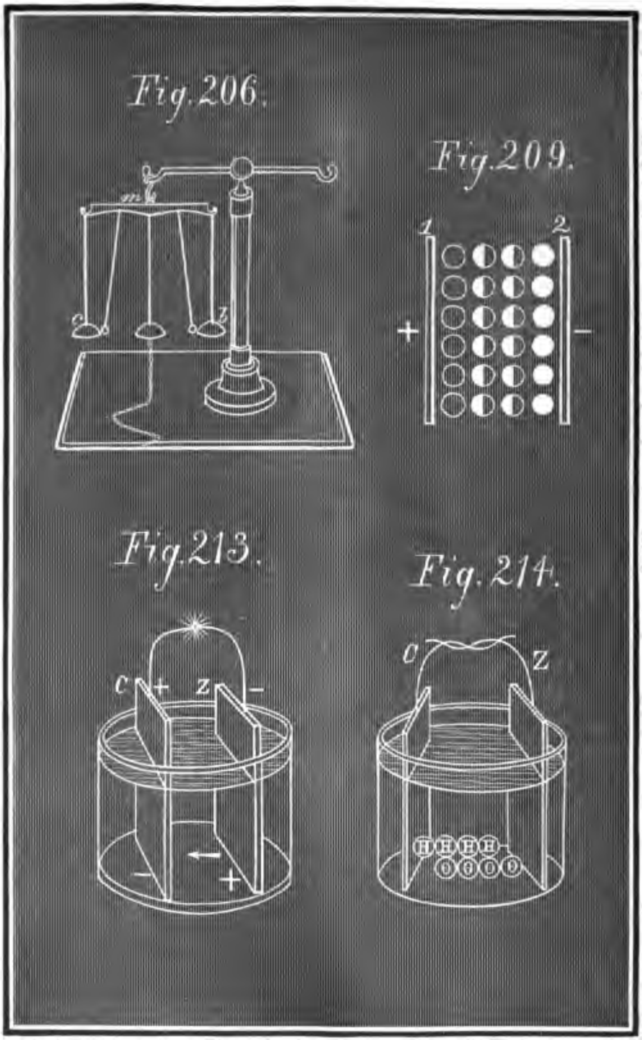

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